



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

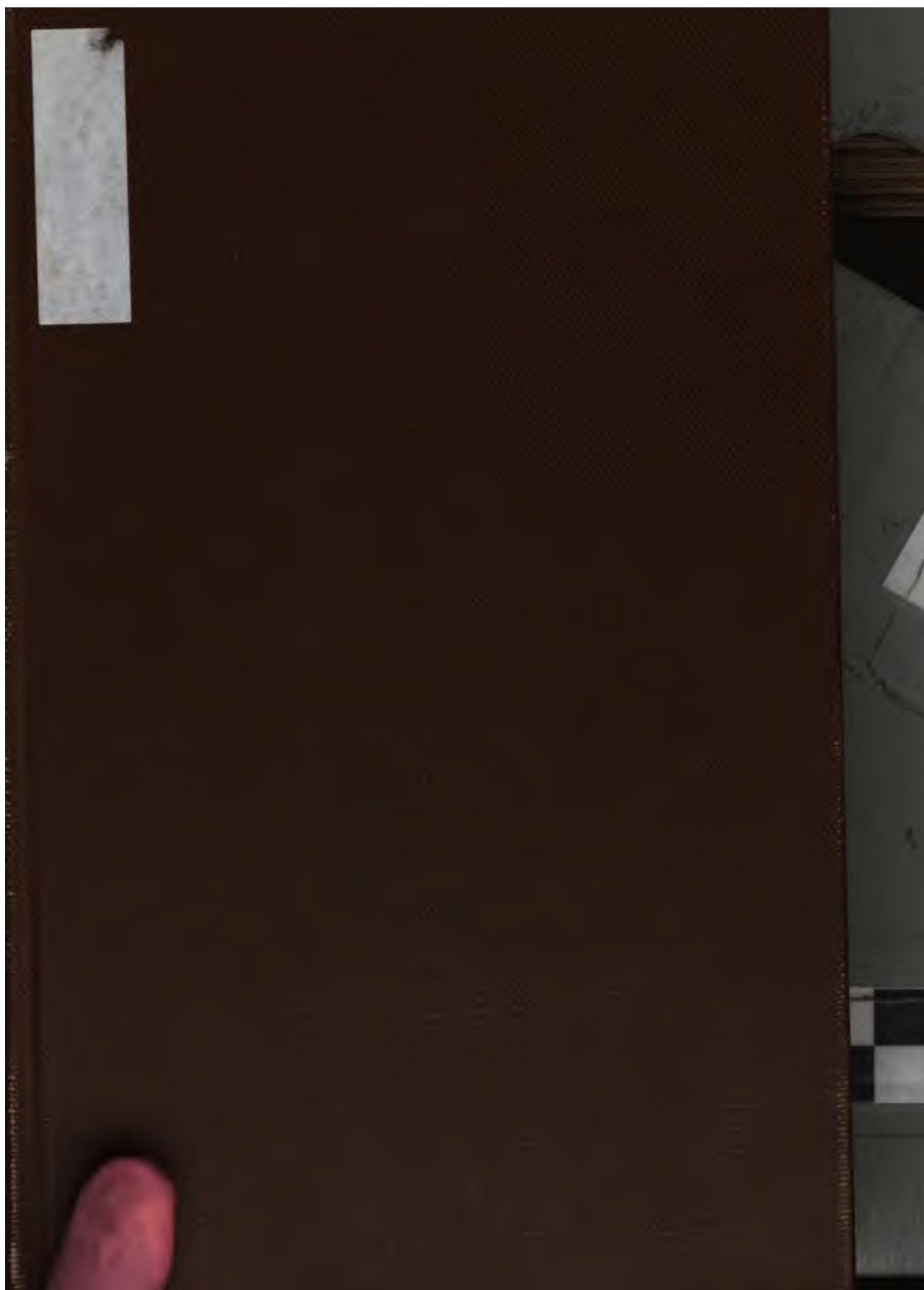
Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>



The Branner Geological Library



LELAND • STANFORD • JUNIOR • UNIVERSITY



The Branner Geological Library



LELAND • STANFORD JUNIOR • UNIVERSITY



DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 55



WASHINGTON
GOVERNMENT PRINTING OFFICE
1889

APOL format

278041

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

REPORT OF WORK DONE

IN THE

DIVISION OF CHEMISTRY AND PHYSICS

MAINLY DURING THE

FISCAL YEAR 1886-'87

FRANK WIGGLESWORTH CLARKE, CHIEF CHEMIST



WASHINGTON
GOVERNMENT PRINTING OFFICE
1889

CONTENTS.

SCIENTIFIC PAPERS.

	Page.
Letter of transmittal.....	9
Studies in the mica groups. By F. W. Clarke	12
The analysis and composition of tourmaline. By R. B. Riggs.....	19
Notes on certain rare copper minerals from Utah. By W. F. Hillebrand and H. S. Washington	38
Mineralogical notes. By W. F. Hillebrand	48
Analyses of some natural borates and borosilicates. By J. Edward Whitfield..	56
On the Johnson County, Ark., and Allen County, Ky., meteorites. By J. Ed- ward Whitfield.....	63
Scorodite from the Yellowstone Park. By J. Edward Whitfield	65
Flow of solids, or behavior of solids under high pressure. By William Hallock.	67

MISCELLANEOUS ANALYSES.

Feldspar from the Hoosac Tunnel.....	79
Two feldspars from Greylock Mountain, Massachusetts	79
Three feldspars from Delaware	79
Triassic sandstone from Maryland	80
Limestone from the Auglaize River, Ohio	80
Twelve rocks from the Menomonee River	81
Rocks from Pigeon Point, Minnesota.....	81
Two rocks from Montana.....	83
Fifteen rocks from California.....	84
Ores of iron and manganese	85
Coals	87
Iron and steel.....	87
Nitre from Utah.....	88
Salt from Warsaw, N. Y.....	89
Two clays from Owen's Lake, California	89
Clay, sand, etc., from Martha's Vineyard	89
Water from Paris, Me	91
Waters from Savannah, Ga	91
Artesian wells in Georgia and Alabama.....	91
Water from Arkansas.....	92
Water from a spring near Fort Wingate, N. Mex	92
Water from Owen's Lake, California.....	93

ILLUSTRATIONS.

Plate I. Diagram of apparatus used in work on high pressure.....	Page. 70
FIG. 1. Crystalline form of olivenite	39
2. Crystalline form of chalcophyllite	43
3. Crystalline form of clinoclasite.....	43
4. Crystalline form of clinoclasite.....	43
5. Crystalline form of clinoclasite.....	44
6. Crystalline form of brochantite.....	46
7. Crystalline form of brochantite	46
8. Crystalline form of brochantite	46
9. Samarskite.....	48
10. Cyrtolite	52
11. Cyrtolite	52
12. Crystalline form of colemanite	57
13. Crystalline form of colemanite	57
14. Diagram of apparatus used in work on high pressures.....	70
15. Diagram of apparatus used in work on high pressures	70
16. Diagram showing experiment	71

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., January 1, 1888.

SIR: This bulletin, like its predecessors—Nos. 9, 27, and 42—represents some of the more important work done in the Division of Chemistry and Physics during one fiscal year. It does not by any means cover all the work completed in the laboratories, but only those portions which were considered far enough advanced for publication. Several other researches are very nearly finished, and will duly appear either as independent bulletins or in the next annual bulletin of the division.

In one investigation we are indebted to Mr. H. S. Washington, of New Haven, for his kind co-operation. His name appears with Dr. Hillebrand's, as joint author of a paper herewith presented.

F. W. CLARKE,
Chief Chemist.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

.

.

.

.

.

SCIENTIFIC PAPERS.

WORK DONE IN THE DIVISION OF CHEMISTRY AND PHYSICS IN 1886-'87.

STUDIES IN THE MICA GROUP.

By F. W. CLARKE.

I. MUSCOVITE FROM ALEXANDER COUNTY, N. C.

This mica occurs in overlapping, crystalline plates, implanted edge-wise in pockets at the well-known locality for emerald and hiddenite at Stony Point. The plates are several centimeters in diameter, with sharply defined crystalline boundaries; and in the specimens before me they are associated with crystallized dolomite, pyrite, and rutile. All of these minerals are more or less dusted over with a dark-green chloritic coating, which, together with some ferruginous staining, gives the mica a somewhat bronzy appearance. An analysis made on carefully purified material gave the following results:

Ignition	5.46
SiO ₂	45.40
TiO ₂	1.10
Al ₂ O ₃	33.66
Fe ₂ O ₃	2.36
MgO	1.86
CaO	none
Li ₂ O	trace
Na ₂ O	1.41
K ₂ O	8.33
F	.69
	100.27
Less oxygen	.29
	99.98

This, except for the presence of titanium, is the composition of an ordinary muscovite. Possibly the titanium may be due to minute inclusions of rutile, but none such were detected. It is more probably present as a replacement either of silica or of alumina.

One of the smaller plates of this mica was examined microscopically by Mr. J. S. Diller, who has kindly furnished the subjoined notes:

The group of muscovite scales shows well-defined crystallographic outlines, most prominent among which are the clinopinacoid and the unit prism, although a small clinodiagonal prism is also common. Parallel with the latter there are indistinct

cleavage lines, which in the basal plane make an angle of 31° with the edge between the basal plane and the clinopinacoid. The angle of the optic axes, measured in oil in a plane perpendicular to the plane of symmetry, is 35° .

The muscovite is partially coated by a greenish dust, which in its arrangement follows crystallographic lines, giving to the scales a streaked appearance. It appears most abundantly upon the prismatic edges, but to a considerable extent also upon the clinopinacoid, and in traces on the clinodiagonal. Thin laminae of dust occur between the foliae of the muscovite, to which they impart a yellowish tinge in reflected light. This dust appears to be weakly doubly refracting, but its structureless character and want of definite optical properties render its determination a matter of difficulty.

With some trouble I collected a little of this chloritic dust, 0.3165 gramme in all, and made a partial analysis of it, as follows:

Ignition	20.50
SiO ₂	31.16
Al ₂ O ₃	8.06
Fe ₂ O ₃	35.86 = 32.28 FeO.
MgO	5.43
	101.01

The iron is undoubtedly present chiefly, but not wholly, in the ferrous state; and the alumina is ascribable to traces of admixed mica. Still, with all its defects, the analysis clearly defines the mineral as a member of the obscure hisingerite group, which has rarely been noted in this country. Its association with pyrite is similar to some of its occurrences abroad, and here, as observed elsewhere, it may originate in the alteration of that species. I hope to give it a fuller examination sometime with a larger supply of material. For the specimens so far studied I am indebted to the kindness of Mr. Wm. Earl Hidden.

II. LEPIDOMELANE FROM BALTIMORE, MD.

This mineral, the characteristic black mica of the Jones Falls pegmatite, was sent me for analysis by Dr. G. H. Williams, of the Johns Hopkins University. The specimen submitted was in broad, brilliant foliations, black by reflected light, but dark smoky green by transmitted light. According to Dr. Williams it is very nearly uniaxial. In the following analysis the direct estimation of water and the determination of ferrous iron were made by Mr. R. B. Riggs:

H ₂ O	4.48
SiO ₂	35.78
Al ₂ O ₃	16.39
Fe ₂ O ₃	14.55
FeO	11.02
MnO	1.08
CaO	none
MgO	8.67
K ₂ O	7.76
Na ₂ O	.56
TiO ₂	none
	100.29

Beckoning the water with the alkalis, the analysis gives approximately the formula $R'_6R''_3R'''_4Si_5O_{22}$. The mineral, therefore, is slightly too basic for an ordinary orthosilicate, and it seems to occupy an intermediate position, as do its ratios, between annite and the Litchfield lepidomelane.

III. LEPIDOMELANE FROM LITCHFIELD, ME.

In a previous paper upon the minerals of Litchfield¹ I gave an analysis of this mica, together with some data as to its occurrence. It is scattered abundantly through the elæolite syenite of the locality, in black brilliant plates or scales, which are transparent only in very thin laminae, and then transmit light of a dark green color. It is one of the least transparent micas I have ever seen. According to Mr. Diller, who kindly made a microscopic examination of the mineral, it is so nearly uniaxial, that a measurement of its optic axial angle is impracticable. Some specimens show evidence of two micas, one being blacker and more brittle than the other, so that a new analysis was made upon very carefully selected material. Only the more transparent and elastic foliæ were chosen, and the results are given below:

H ₂ O	4.67
SiO ₂	32.35
Al ₂ O ₃	17.47
Fe ₂ O ₃	24.22
FeO	13.11
MnO	1.02
CaO	.89
MgO	none
Na ₂ O	.70
K ₂ O	6.40
TiO ₂	none
	100.83

THE DETERMINATIONS FOR IRON IN THE FERROUS STATE AND FOR WATER.

The ferrous iron and water determinations were made by Mr. Riggs. Titanium was carefully sought for by two methods in three separate tests, but only a doubtful trace was discovered. The formula of the mica, reckoning water with the alkalis, is very nearly $R'_6R''_2R'''_6Si_5O_{24}$.

This mica, on account of its low percentage of silica and its basic nature, has peculiar interest. Among published analyses of micas I find only two which approach it in these particulars, namely the micas from Brevig and Miask, described by C. Rammelsberg.² These gave respectively 32.97 and 32.49 per cent. of silica, but they also contained, the first 2.42 and the second 4.03 of titanous oxide. This constituent, as

¹ Bull. U. S. Geological Survey, No. 42, p. 35.

² Geol. Gesell. Zeitschr., vol. 31, 676-691.

has been stated, is lacking in the Litchfield mineral. Notably all three of these low silica micas are from localities of *elæolite* syenite, although Rammelsberg says nothing of the actual associations of the specimens discussed by him. The question at once arises, to be settled by future investigation, whether micas of this peculiar character are representative of *elæolitic* rocks, and whether there is any genetic relation between them and *eleolite*. I hope that observations upon this point may soon be multiplied.

Some months ago I published some analyses of the Rockport micas, which were made by Mr. Riggs in this laboratory.¹ One of these, the so-called *annite*, seems to have a serial relation with the analogous micas from Baltimore and Litchfield, which may be expressed in formulæ. These, stated in empirical form, are as follows:

Rockport.....	$R'_6R''_4R'''_2Si_6O_{30}$
Baltimore.....	$R'_6R''_3R'''_4Si_6O_{32}$
Litchfield.....	$R'_6R''_2R'''_6Si_6O_{34}$

Here we have R' and silicon constant, while a gain of R'''_2O_2 corresponds in each step to a loss of one atom of R'' . If now we assume that R'''_2O_2 represents really two of the recognized univalent groups $-Al=O$, we shall find that all three of the micas, reduce to the true orthosilicate type, containing the nucleus $R'''_2(SiO_4)_3$, which appears to be characteristic of many iron micas and of the *phlogopite* group. We thus have, uniting all the monoxide bases, the following general formulæ:

Rockport.....	$R'_{14}R'''_2(SiO_4)_3$
Baltimore.....	$R'_{12}(AlO)_2R'''_2(SiO_4)_3$
Litchfield.....	$R'_{10}(AlO)_4R'''_2(SiO_4)_3$

In short, the three micas are built upon the same fundamental plan, and exhibit a new and highly suggestive order of variation.

IV. IRON-BIOTITE FROM AUBURN, ME.

Among the minerals occurring at the well-known *lepidolite* locality at Auburn a brilliant black *biotite* is common. Some time since, in looking over a collection of the Auburn material in the possession of Mr. N. H. Perry, of South Paris, I observed that certain broad foliæ of this mica were bordered by a grayish distinct margin, about 5^{mm} wide, which was made up of micaceous scales. Inasmuch as the *lepidolite* of the locality forms similar borders upon the *muscovite*, I thought that this bordering might have interest, and Mr. Perry kindly placed his best specimen at my disposal. Analyses of both the *biotite* and the margin were made, but unfortunately the amount of the latter available was too small for complete investigation. In the study of the border, therefore, ferrous iron and water had to be neglected, and that analysis is

¹ Bull. U. S. Geological Survey, No. 42, p. 22.

so far incomplete. The results are given below, with determinations of water and ferrous iron in the biotite made by Mr. Riggs:

	Biotite.	Margin.
H ₂ O.....	4.64	undet.
SiO ₂	34.67	56.44
Al ₂ O ₃	30.09	16.01
Fe ₂ O ₃	2.42	} 15.91
FeO.....	16.14	
MnO	.85	undet.
MgO	1.98	.97
CaO	none	none.
Na ₂ O.....	1.67	1.92
K ₂ O.....	7.55	6.15
F	.28	.71
	100.29	
Less oxygen.....	.12	
	100.17	

Upon microscopic examination by Mr. Diller the mica was found to be "almost completely uniaxial, for when it was rotated between crossed nicols the displacement of the black cross was scarcely perceptible." He also found that the same mica, with a slight change of color from brown to greenish brown, continued into the border, where it was intimately mingled with grains and fibers of quartz. The latter admixture accounts in part for the high percentage of silica in the margin, although it seems probable that there may be also some degradation from the original orthosilicate toward a metasilicate type. At all events the specimens are in nowise analogous to those which show lepidolite borders upon muscovite.

In its ratios this Auburn mica is not simple. Approximately, reducing all monoxides to the univalent type, its formula may be written $R'_{11}(AlO)_3Al_2(SiO_4)_5$; with $R'_{11} = H_4K_2Fe_{3\frac{1}{2}}$. It seems to be a compound intermediate between the Litchfield and Baltimore micas, with R''' nearly all aluminum.

V. IRON-MICA FROM THE VICINITY OF PIKE'S PEAK.

This specimen, which was kindly given me by Mr. C. S. Bement, was a section from a large prismatic crystal in his collection. It was a bronzy black mica, resembling phlogopite externally, but remarkably altered at the center. The entire core of the crystal was made up of a soft, rotten material, evidently derived from the original mica, and surrounded by a broad black margin of the latter. Streaks of rusty alteration products reached into the margin in every direction, so that no

absolutely unchanged material could be obtained for analysis. According to Mr. Diller, the angle of the optic axes is too small for measurement.

Analyses were made of both margin and center, the former being little altered, the latter as much altered, as could be selected.

Again I am indebted to Mr. Riggs for determinations of water ferrous iron :

	Margin.	Center.
H ₂ O.....	4.54	Ignition 7.82
SiO ₂	34.21	34.63
Al ₂ O ₃	16.53	17.95
Fe ₂ O ₃	20.15	31.25
FeO.....	14.17	3.01
MnO	.91	.34
CaO	.48	.81
MgO	1.34	1.08
Na ₂ O.....	1.43	.89
K ₂ O.....	6.50	1.96
F	.08	.54
	100.34	100.28
Less O	.03	.23
	100.31	100.05

These figures show the order of alteration so well, that comment on them is unnecessary. The original mica probably was very near Leucosiderophyllite, but it is hardly worth while to discuss the ratios.

THE ANALYSIS AND COMPOSITION OF TOURMALINE.

BY R. B. RIGGS.

Apart from the work by Rammelsberg¹ very little has been done towards solving the question of the composition and constitution of tourmaline. Its apparent complexity and the difficulties attending the determination of certain constituents have doubtless turned many aside, possibly also the impression that with Rammelsberg's investigations the matter was settled. While Rammelsberg's work was comprehensive, and was possibly good for the times, his analyses are so seriously faulty in certain important respects as to justify a new investigation. Though the direct estimation of both water and boric acid would seem to be of the highest importance before any satisfactory conclusions could be reached with reference to the constitution of tourmaline, we find that, having failed in one single attempt to determine the water directly, he takes the loss on ignition, deducts therefrom an amount equal to the amount of silicon tetrafluoride, representing the fluorine found in the mineral, and calls the rest water. He takes it for granted that the fluorine is driven off quantitatively. While this supposition is questionable, it is not the main ground of objection. In the revision² of his earlier work Rammelsberg comes to the conclusion that the iron contained in tourmaline is all there in the ferrous condition, yet he wholly ignores the fact of its possible oxidation on ignition, especially an ignition such as would be necessary to expel the fluorine.

In a few cases boric acid was determined directly, but by a method (Stromeyer's) which has ever been counted as one of the most unsatisfactory. In the majority of analyses boric acid was estimated by difference. But if the results called water are incorrect and low, as they surely are, the boric acid ought to be correspondingly high, or the analysis must be faulty in other respects.

The direct estimation of water being possible, and a satisfactory method for determining boric acid having lately been devised by Dr. F. A. Gooch,³ new tourmaline analyses seemed desirable.

¹ Pogg. Ann., vol. 80, p. 449; vol. 81, 1 p.; vol. 139, pp. 379, 547.

² Pogg. Ann., vol. 139, p. 379.

³ Bull. U. S. Geological Survey, No. 42, pp. 64-72.

SCIENTIFIC PAPERS.

(4) Convinced, by the summations of some of the analyses and by comparing the loss on ignition with the corresponding direct water determinations, that the iron in tourmaline must be there, in large part at least, in the ferrous condition, I finally heated the mineral with hydrofluoric and sulphuric acids in the closed platinum crucible over the direct flame, thus digesting at a moderately high temperature and a correspondingly high pressure, and at the same time securing a constant agitation of the powdered mineral. In these determinations a thin lead washer replaced the rubber. Half an hour with these conditions usually sufficed to effect complete decomposition. The crucible was cooled in an atmosphere of carbon dioxide and the iron was determined in the usual way with a potassium permanganate solution. Fair results were obtained, such as to indicate that the iron in tourmaline is there chiefly in the ferrous condition; the conclusion which Rammelsberg reached as the result of Mitscherlich's experiments¹, confirmed by a few determinations of his own.

Alkalies.—Several vain attempts were made to decompose the tourmaline with hydrofluoric and sulphuric acids. As showing the refractory nature of the mineral, the following is a case in point: One gramme of the pale green Auburn variety, after being ignited, was evaporated to dryness with about 20^{cc} of hydrofluoric acid five times and left an insoluble residue of 0.473 gramme. The Lawrence Smith method was finally adopted, and with highly satisfactory results. The only precautions necessary are that the mineral be finely powdered, and that the mixture with ammonium chloride and calcium carbonate be intimate, which latter condition is only to be secured by grinding the several ingredients together. When these conditions are all that they should be, there is no trouble in bringing about complete decomposition in the course of an hour's gentle ignition. After the alkalies have been leached out with water, the residue should of course be treated with acid to test the completeness of the disintegration. In the case of the tourmalines, with their low silica percentages, the solution is usually complete if the decomposition has been perfect. After the alkalies have been freed from the other bases by the usual well-known methods, although the greater part of the boric acid will have been driven off by the repeated evaporations, more or less of it remains. This residual amount is removed by two or three evaporations with methyl alcohol. The separation of lithia from the other alkalies was made by the Gooch method,² by boiling the mixed chlorides in amyl alcohol, and further separations were effected in the usual way.

Silica.—On the strength of the belief that tourmaline sometimes contains fluorine in considerable amounts, the silica was at first estimated by precipitating it with carbonate of ammonia. Where the bases thrown down by this reagent are so in excess of the silica as they are in tourmaline, its precipitation is fairly easy and quantitative.

¹ Jour. Prakt. Chemie, vol. 86, p. 1.

² Bull. U. S. Geol. Survey, No. 42.

Nevertheless, where this method was used, of duplicate determinations the higher is taken in the summation. Save where the silica is greatly in excess of the bases thrown down by ammonium carbonate, the addition of zinc compounds, as is commonly recommended, is wholly unnecessary. In fact, even in dealing with such minerals as the lepidolites, which contain about 50 per cent. of silica and only 30 per cent. of alumina, the addition of zinc compounds gives no better results than are obtained by simple evaporation with carbonate of ammonia, the evaporation being repeated several times.

As soon as it became evident that the amount of fluorine, if present at all, was so small that its influence in carrying off silica could be neglected, the ordinary method of separation was employed. In all cases silica was corrected by evaporation with hydrofluoric acid.

Alumina.—The only point worthy of mention in this connection is the necessity of testing the alumina for the silica which it frequently contains. This is usually done by fusing the ignited product with potassium bisulphate. Where it amounts to as much as it does in tourmaline, generally exceeding four-tenths gramme, a carbonate of soda fusion works more satisfactorily; it can be continued longer and at a higher temperature. This fusion is readily converted into a sulphate fusion, and the desired separation is thus accomplished. Several fusions are sometimes necessary to bring the bases into solution. As regards other determinations nothing in particular need be said.

ANALYSES.

Analyses have been made of material from the following localities: Auburn, Rumford, and Paris, Me.; Calhao, province of Minas Geraes, Brazil; De Kalb, Gouverneur, and Pierrepont, N. Y.; Hamburgh, N. J.; Orford, N. H.; Monroe and Haddam, Conn.; Stony Point, N. C.; and Nantic Gulf, Baffin Land, well representing the variations in physical properties and chemical composition which characterize the different varieties of tourmaline.

For the sake of compactness the results of these analyses have been grouped. The tourmalines from Maine and those from Brazil are thrown together according to localities, though, barring the iron varieties, they should be classed together on the basis of their composition, on which basis those from other localities are roughly grouped.

Maine.—These tourmalines occur in veins of albitic granite, the chief constituents of which are quartz, albite, and muscovite, with lepidolite and beryl as important accessories. At Rumford spodumene is abundant.

Auburn.—A. Colorless to very pale green crystals, some of which were tinged faintly pink and blue, infusible. Sp. gr., 3.07. B. Light green, fragile crystals, infusible. C. Dark green, massive tourmaline;

difficulty. D. Massive black tourmaline, easily fusible. Sp.

A.		B.		C.		D.	
I.	II.	I.	II.	I.	II.	I.	II.
1	38.00	37.85	37.80	36.26	36.18	34.99	34.87
0		37.73		36.68		33.96	
0	41.37-41.48	.42	42.37-42.54	.15	44.65-44.73	none	49.76-49.79
8		3.88		7.07		14.23	
e		none		none		none	
e		trace		trace		trace	
8		.51		.72		.06	
3		.49		.17		.15	
e		.04		.16		1.01	
4		1.34		1.05		trace	
6		2.16		2.88		2.01	
7		.62		.44		.34	
6	4.06- 4.26	4.18	4.16- 4.20	4.05	4.00- 4.11	3.62	3.56- 3.68
25	10.15-10.34	10.55		9.94	9.83-10.04	9.63	9.44- 9.82
2	.72	.62	.72	.71	.80	none	
23		100.39		100.28		100.00	
8		.26		.30			
7		100.13		99.98			

material for the above analyses was received from Mr. N. H. South Paris, Me.

d, *Black Mountain*.—A. Massive, rose-colored, infusible. G.,

sive, dark green; fuses with difficulty.

fount Mica.—Massive, black, powder blue-black, easily fusible.

A.		B.		Paris.	
I.	II.	I.	II.	I.	II.
38.07	38.02	36.53	36.42	35.03	34.99-35.06
42.24		38.10		34.44	
	42.44-42.64	none		1.13	
.26		6.43		12.10	
none		trace		trace	
.35		.32		.08	
.56		.34		.24	
.07		none		1.81	
1.59		.95		.07	
2.18		2.86		2.03	
.44		.38		.25	
4.26	4.25- 4.28	3.52	3.44- 3.60	3.69	3.63- 3.75
9.99	9.85-10.13	10.22	10.03-10.41	9.02	8.92- 9.12
.28		.16		none	
100.29		99.81		99.89	
1 .12		.07			
100.17		99.74			

For the Rumford material I am indebted to Mr. E. M. Bailey, of Andover, Me. The Paris tourmalines was kindly furnished me out of the National Museum collection.

In connection with the Maine tourmalines the following interesting alteration products were studied :

- A. An alteration from the light green Auburn (B) variety.
- B. Flesh-colored alteration product from the Rumford locality.
- C. An alteration from the Hebron rubellite.

	A.	B.	C.
SiO ₂ .....	.....	53.03	43.90
Al ₂ O ₃ .....	.....	31.67	38.71
Fe ₂ O ₃ .....	.....	.51	.58
FeO .....	.....	.....	.25
MnO .....	.....	trace	.04
CaO .....	.....	trace	.41
MgO .....	.....	trace	.05
Li ₂ O	2.86	.26	.....
Na ₂ O	2.16	.54	1.05
K ₂ O	9.64	9.44	10.92
H ₂ O .....	.....	4.80	4.25
B ₂ O ₃	trace	trace	trace
F .....	.....	trace?	none
		100.25	100.16

While the light green Auburn tourmalines were mostly translucent crystals, a few were found which, having become partially opaque, had assumed a micaceous structure. With scant material only the above partial analysis was possible. The results indicate a change in the direction of lepidolite.

The Rumford alteration was examined microscopically by Mr. J. S. Diller, who observed as follows:

Under the microscope it is seen to be composed of two minerals most thoroughly intermingled in nearly equal proportions. One of these minerals is micaceous in structure, with strong double refraction like damourite, which it closely resembles in general appearance. The other mineral is clear, colorless, and apparently monoclinic, with a rather low index of refraction and moderately intense double refraction.

While the Hebron rubellite alteration retains its crystalline form, its material is altered into a softer mineral of an opaque, talcose appearance. The analysis shows the change to be towards damourite,¹ and not towards lepidolite as has been supposed.

Brazil.—Cachao, province of Minas Geraes. The association of these tourmalines I was unable to find out. From their composition, however, it is probable that it does not differ greatly from that of the Maine varieties. The specimens analyzed were supplied by Mr. G. F. Kunz.

A. The pink, almost colorless, center of crystals having a green border, infusible. Sp. gr., 3.028.

B. Pale green, like the border of A, infusible.

C. Olive green, fusible in very thin splinters.

¹ F. W. Clarke, U. S. Geological Survey, Bulletin No. 42, p. 15.

¹ D. Black, in splinters a smoky blue green, fuses easily. Sp. gr., 3.20.

	A.		B.		C.		D.	
	I.	II.	I.	II.	I.	II.	I.	II.
SiO ₂	37.19	 37.12	37.39	 37.31	36.91		34.63	34.50
Al ₂ O ₃	42.43	} 42.94-43.06	39.65	} 42.30-42.38	38.13		32.70	
Fe ₂ O ₃	none		.15		.31		.31	
FeO.....	.52		2.29		3.19		13.69	
P ₂ O ₅	none		trace		.11		none	
MnO.....	.79		1.47		2.22		.12	
CaO.....	.57		.49		.38		.33	
MgO.....	none		none		.04		2.13	
Li ₂ O.....	1.73		1.71		1.61		.08	
Na ₂ O.....	2.24		2.42		2.70		2.11	
K ₂ O.....	.23		.25		.28		.24	
H ₂ O.....	3.90	3.86- 3.93	3.63	3.60- 3.66	3.64		3.49	3.42-3.56
B ₂ O ₃	10.06	9.96-10.16	10.29	10.10-10.49	9.87	9.85-9.88	9.63	9.55-9.70
F.....	trace?		.32	41	.14	17	.06	10
	99.66		100.06		99.53		99.52	
Less oxygen.....			.13		.06		.02	
			99.93		99.47		99.50	

De Kalb, St. Lawrence County, N. Y.—Colorless to light brown translucent crystals in calcite, with quartz and titanite inclusions, easily fusible. Sp. gr., 3.085.

Gouverneur, St. Lawrence County, N. Y.—Brown, associated with calcite, easily fusible.

Hamburgh, N. J.—Large, cinnamon brown crystals, associated with calcite, quartz, and colorless mica, with many small, shiny, black scales of titanite, easily fusible.

	De Kalb.		Gouverneur.		Hamburgh.	
	I.	II.	I.	II.	I.	II.
SiO ₂	36.98		37.39	37.33-37.45	35.25	
Al ₂ O ₃	28.87		27.79		28.49	
Fe ₂ O ₃			.10		none	
FeO.....	.52		.64		.86	
TiO ₂	.12		1.19		.65	
P ₂ O ₅	undet.		none		trace	
MnO.....	none		none		none	
CaO.....	3.70		2.78		5.09	
MgO.....	14.53		14.09		14.58	
SrO.....	trace		trace		trace	
BaO.....	none		none		none	
Li ₂ O.....	trace		trace		trace	
Na ₂ O.....	1.39		1.72		.94	
K ₂ O.....	.18		.16		.18	
H ₂ O.....	3.56	3.55- 3.57	3.83	3.77- 3.89	3.10	3.02-3.18
B ₂ O ₃	10.58	10.46-10.70	10.73	10.63-10.83	10.45	
F.....	.50		trace?		.78	
	100.83		100.42		100.37	
Less oxygen.....	.21				.33	
	100.62				100.04	

For the De Kalb and Hamburg tourmaline I am indebted to Mr. G. F. Kunz. The Gouverneur material was from the National Museum collection.

From the large amount of titanite oxide found in the Gouverneur specimen it was feared that it might be there as an impurity. On examining a section microscopically Mr. Diller found it, on the contrary, to be quite free from inclusions of any kind. Specimens from other Gouverneur localities, viz, from the town of Gouverneur itself and from Reese's farm, 7 miles north of the town, were also found to contain the oxide in large amounts.

Orford, N. H..—Dark brown crystals, in chloritic schist, easily fusible.

Monroe, Conn..—Dark brown crystals, in chloritic schist, easily fusible.

	Orford.		Monroe.	
	I.	II.	I.	II.
SiO ₂	36.66		36.41	
Al ₂ O ₃	32.84		31.27	
Fe ₂ O ₃	none		none	
FeO	2.50		3.80	
TiO ₂	.23		1.61	
P ₂ O ₅	none		trace	
MnO	trace		trace	
CaO	1.35		.98	
MgO	10.35		9.47	
SrO	trace		trace	
BaO	none		none	
Li ₂ O	trace		none	
Na ₂ O	2.42		2.68	
K ₂ O	.22		.21	
H ₂ O	3.78	3.77- 3.79	3.79	3.76-3.82
B ₂ O ₃	10.07	9.86-10.28	9.65	9.57-9.73
F	trace ?		none	
	100.42		99.87	

The Orford material was received from Prof. C. H. Hitchcock. The Monroe specimens came from the National Museum collection. The schistose gangue, in which the tourmalines from Orford and Monroe are imbedded, is of particular interest, and was studied microscopically as well as chemically, in the hope that it might throw light on the genetic relations of magnesian tourmaline. The microscopic work, which was of special importance, was kindly undertaken by Mr. J. S. Diller.

Chemical analysis.

Constituents.	Orford.	Monroe.
SiO ₂	27.18	43.30
Al ₂ O ₃	33.10	27.44
CaO	.19	1.96
MgO	28.09	19.22
Na ₂ O	undet.	1.47
K ₂ O	undet.	.60
Ignition	11.75	1.45
	100.31	101.44

While Mr. Diller found the Orford matrix to be essentially chlorite, in agreement with the results of chemical analysis, the gangue rock of the Monroe tourmaline turned out to be particularly interesting.

Of this Mr. Diller says:

This light gray glittering rock is composed chiefly of biotite, chlorite, and a light-colored mineral which may possibly be zoisite. The biotite is very dark and apparently uniaxial and negative with all the other physical properties of the species. The chlorite is much paler than the biotite and of a greenish color. It is distinctly biaxial, with a small optic angle and positive. The relation of the chlorite to the biotite is readily seen in the thin sections, where it evidently is derived from the latter by a process of alteration. An interesting feature is that in the immediate vicinity of the imbedded tourmaline the biotite is all changed to chlorite, and is arranged with its folia approximately perpendicular to the crystallographic planes of the tourmaline, against which it impinges. The chlorite completely envelopes the tourmaline, and the other portions of the hand specimen are made up chiefly of biotite and the zoisitic mineral with a small proportion of chlorite. This variation in the mineralogical composition of the hand specimens readily explains the discrepancy that at first appeared to exist between the results of chemical analysis and my observations.

That the analysis represents a portion of the rock rich in chlorite and poor in biotite, the high magnesia and low alkalis plainly show. The relation existing between the biotite, the chlorite, and the tourmaline in this Monroe matrix is of importance, indicating, as suggested, the transition to be from the mica through the chlorite to the tourmaline.

Pierrepont, St. Lawrence County, N. Y.—Perfect black crystals, highly modified, associated with calcite; fuses easily. Sp. gr., 3.08.

Nantic Gulf, Cumberland, Baffin Land.—Large black crystal, easily fusible. Sp. gr., 3.095.

Stony Point, Alexander County, N. C.—Perfect, medium-sized, black crystals, from the hiddenite mine, with implanted crystals of quartz. The associated minerals are chiefly quartz, muscovite, apatite, rutile, beryl, and spodumene; fuses easily. Sp. gr., 3.13.

Haddam, Conn.—Black crystals in quartz and feldspar, powder blue black, easily fusible.

	Pierrepont.		Nantic Gulf.		Stony Point.		Haddam.	
	I.	II.	I.	II.	I.	II.	I.	II.
SiO ₂ ...	35.61		35.34		35.56		34.95	
Al ₂ O ₃ ..	25.29		30.49		33.38		31.11	
Fe ₂ O ₃ ..	.44		none		none		.50	
FeO...	8.19		8.22		8.49		11.87	
TiO ₃ ...	.55		.40		.55		.57	
P ₂ O ₅ ...	trace		none		?		trace	
MnO ..	trace		trace		.04		.09	
CaO...	3.31		2.32		.53		.81	
MgO ..	11.07		7.76		5.44		4.45	
SrO ...	none		trace		none		none	
BaO...	?		?		none		none	
Li ₂ O...	trace		trace		trace		trace	
Na ₂ O ..	1.51		1.76		2.16		2.22	
K ₂ O ...	.20		.15		.24		.24	
H ₂ O...	3.34	3.30- 3.37	3.60	3.53- 3.67	3.63	3.57- 3.69	3.62	3.58- 3.66
B ₂ O ₃ ..	10.15	10.00-10.31	10.45	10.30-10.60	10.40		9.92	9.74-10.10
F	.27		none		none		none	
	99.93		100.49		100.42		100.35	
Loss O.	.11							
	99.82							

Mr. W. E. Hidden very kindly furnished the Stony Point material. For the other specimens I am a debtor to the National Museum collection. The gravity determinations of the Pierrepont, Stony Point, and Nantic Gulf tourmalines were kindly made by Dr. William Halleck.

From the above analyses it is at once apparent that we have three types to deal with, lithia, iron, and magnesian tourmalines, respectively, with an indefinite number of intermediate products.

For comparison's sake I have tabulated these results, arranging them so as best to show how these types graduate from one into the other, beginning with the lithia tourmaline and passing thence through the iron varieties to those of the purest magnesian type. To render it a complete table of tourmaline analyses, so far as such analyses are worth considering, the results of Rammelsberg's extensive work are added, given in the order and grouping found in his revision of the subject.¹ Also an analysis of an interesting chrome-tourmaline from the Ural, by A. Cossa and A. Arzruni;² the only one of a small number of scattering analyses which seemed to have any value from an analytic standpoint.

¹ Ramm. Handb. d. Min. Chem., 1875, 538-544; Pogg., lxxx, 449, lxxxi, 1.

² Zeit. Kryst. und Min., vol. 7, 1.

WASHINGTON LABORATORY.

[BULL. 35.]

Localities.	B ₂ O ₃	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	MnO	CaO	MgO	Li ₂ O	Na ₂ O	K ₂ O	H ₂ O	F	Total.	Ign.
Rumford (A)	9.99	38.07	42.24	.26	none	none	.35	.56	.07	1.59	2.18	.44	4.26	.28	100.17	4.35
Brazil (A)	10.06	37.19	42.43	.52	(f)	none	.79	.57	none	1.73	2.24	.23	3.90	trace	99.66	4.10
Auburn (A)	10.23	38.14	39.60	.30	1.38	trace	1.38	.43	none	1.34	2.36	.27	4.16	.62	98.97	4.09
Brazil (B)	10.29	37.39	39.65	.15	2.29	(f)	1.47	.49	none	1.71	2.42	.25	3.63	.31	98.93	.....
Auburn (B)	10.55	37.85	37.73	.42	3.83	trace	.51	.49	.04	1.34	2.16	.62	4.18	.62	100.13	.....
Brazil (C)	9.87	36.91	38.13	.31	3.19	(f)	2.22	.38	.04	1.61	2.70	.28	3.64	.14	98.47	3.62
Rumford (B)	10.22	36.53	38.10	none	6.43	(f)	.32	.34	none	.95	2.86	.38	3.49	.16	99.71	3.31
Auburn (C)	9.94	36.26	36.08	.15	7.07	none	.72	.17	.16	1.05	2.68	.44	4.05	.71	98.98	.....
Paris	9.02	35.03	34.44	1.13	12.10	(f)	.08	.24	1.81	.07	2.03	.25	3.09	none	98.89	2.36
Auburn (D)	9.63	34.99	33.96	none	14.23	none	.06	.15	1.01	trace	2.01	.34	3.62	none	100.00	2.17
Brazil (D)	9.63	34.63	32.70	.31	13.69	(f)	.12	.33	2.13	.08	2.11	.24	3.49	.06	99.50	2.19
Haddam	9.92	34.96	31.11	.50	11.87	.57	.09	.81	4.45	trace	2.22	.24	3.62	none	100.35	2.41
Nantic Gulf	10.40	35.56	33.38	none	8.49	.55	.04	.53	5.44	trace	2.16	.24	3.63	none	100.42	2.88
Stony Point	10.45	35.34	30.49	none	8.22	.40	trace	2.32	7.76	trace	1.76	.15	5.60	none	100.49	2.86
Pierpont	10.15	35.61	25.29	.44	8.19	.55	trace	3.31	11.07	trace	1.51	.20	3.34	.27	99.82	2.69
Monroe	9.65	36.41	31.27	none	3.80	1.61	trace	.96	9.47	none	2.66	.21	3.79	none	99.87	3.59
Orford	10.07	36.66	32.84	none	2.50	.23	trace	1.36	10.35	trace	2.42	.22	3.76	trace	100.42	.....
Gouverneur	10.73	37.39	27.79	.10	.64	1.19	none	2.78	14.09	trace	1.72	.16	3.38	trace	100.42	.....
DeKalb	10.58	36.88	28.87	none	.52	(f)	none	3.70	14.53	trace	1.39	.18	3.56	.50	100.62	.....
Hamburgh	10.45	35.25	28.49	none	.86	.65	none	5.09	14.58	trace	.94	.18	3.10	.78	100.04	.....

Analyses by Rammeisberg.

Localities.	B ₂ O ₃	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	TiO ₂	P ₂ O ₅	MnO	CaO	MgO	Li ₂ O	Na ₂ O	K ₂ O	H ₂ O	F	Total.	Ign
1. Gouverneur.....	(8.35)	38.85	31.32	.....	1.14	.....	.....	.....	1.00	64.89	.....	1.28	.26	2.31	.....	100.00	3.19
2. W. Kappel.....	11.15	38.09	32.90	.....	.06	.....	.....	.....	1.25	11.70	.....	2.37	.47	2.05	.64	101.37	2.93
3. Eibenstock.....	(9.14)	37.75	30.86	.....	4.36	.....	.....	.....	.88	11.62	.....	2.27	.90	2.82	.....	100.00	3.50
4. Zillerthal.....	(9.53)	38.51	32.65	.....	2.90	.....	.....	.36	.16	10.46	.....	2.13	.37	3.04	.36	100.36	3.54
5. Orford.....	9.46	38.33	33.15	.....	2.88	.....	.....	.....	.77	10.89	.....	1.53	.....	2.81	.....	100.21	3.49
6. Texas.....	(8.57)	38.45	34.56	.....	2.08	.....	.....	.09	.71	9.11	.....	2.00	.75	2.80	.....	100.00	3.30
7. Monroe.....	(8.93)	39.01	31.18	.....	4.07	.....	.....	.....	1.81	9.90	.....	1.82	.44	2.82	.....	100.00	3.32
8. Godhaab.....	(7.82)	37.70	34.26	.....	4.42	.....	.....	.....	1.25	9.51	.....	2.00	.43	2.61	.....	100.00	3.11
9. Havredal.....	(9.29)	37.11	31.26	.....	7.58	.....	.....	.....	.80	9.43	.....	1.78	.32	2.43	.....	100.00	.....
10. Goth rd.....	(10.32)	38.00	31.41	.....	7.23	.....	.....	.....	1.31	7.27	.....	1.43	.28	2.75	.....	100.00	3.25
11. Haddam.....	(9.02)	37.50	30.87	.....	8.54	.....	.....	.....	1.33	8.60	.....	1.00	.73	1.81	.....	100.00	3.44
12. Ramfossen.....	(9.73)	37.22	30.00	.....	11.16	.....	.....	.....	.65	7.94	.....	1.13	.53	1.64	.55	100.55	.....
13. Elba, black.....	(9.03)	38.20	30.02	.....	9.93	.....	.....	.58	.74	6.77	.....	2.19	.25	2.29	.15	100.15	.....
14. Unity.....	(9.04)	38.29	30.44	.....	13.23	.....	.....	.....	1.02	6.82	.....	1.94	.....	1.72	.....	100.00	2.23
15. Krumman.....	(9.82)	36.43	34.12	.....	11.58	.....	.....	.....	.44	3.84	.....	1.36	.30	2.11	.....	100.00	2.66
16. DeKalb.....	(9.70)	37.07	31.86	.....	12.55	.....	.....	.51	.....	3.49	.....	2.04	.30	2.48	.81	100.31	.....
17. Langenhielan.....	(11.02)	37.24	31.63	.....	11.64	.....	.....	.....	.62	3.68	.....	1.93	.82	1.45	.....	100.00	.....
18. Bovey Tracy.....	(10.72)	37.94	30.22	.....	13.82	.....	.....	.40	.50	2.62	.....	1.39	.65	1.74	.45	100.45	2.09
19. Krumbach.....	(10.27)	36.25	32.21	.....	12.82	.....	.....	1.50	.40	2.32	.....	1.43	.46	2.34	.64	100.64	.....
20. Alabashka.....	(12.79)	36.19	30.41	.....	15.59	.....	.....	.54	.....	1.88	.....	1.02	.47	1.11	.76	100.76	.....
21. Andreasberg.....	(11.11)	36.06	30.34	.....	17.40	.....	.....	.11	.72	.....	.....	1.36	.58	1.54	.85	100.85	.....
22. Saas.....	11.64	36.11	35.46	.....	13.17	.....	.....	.28	.....	1.52	.....	.98	.09	1.26	.81	100.92	.....
23. Sarapulsk.....	(11.63)	38.30	31.53	.....	10.30	.....	.....	2.68	.....	1.06	trace.	2.37	.33	1.81	.80	100.80	3.28
24. Gosben.....	10.65	36.22	33.35	.....	11.95	.....	.....	1.25	.....	.63	.84	1.75	.40	2.21	.82	100.82	.....
25. Ellva.....	(9.37)	37.14	34.15	.....	10.52	.....	.....	1.87	.....	1.68	.32	2.30	.75	1.90	.47	100.47	.....
1. Elba, green.....	(9.99)	37.74	41.89	.....	1.38	.....	.....	2.51	.....	.41	.74	2.40	.34	2.60	.50	100.50	.....
2. Schaitanek.....	(9.29)	38.26	43.97	.....	.....	.....	.....	1.53	.62	1.60	.48	1.53	.21	2.49	.70	100.70	3.45
3. Paris.....	9.97	38.19	42.63	.....	.....	.....	.....	4.94	.45	.39	.....	1.17	.68	2.00	1.18	101.20	3.61
4. Potosi.....	(8.93)	41.16	41.83	.....	.....	.....	.....	.96	.....	.61	.41	1.37	2.17	2.57	1.19	101.19	3.76

[BULL. 5

	(10, 09)	38.06	37.81	5.83	.....	1.13	.92	1.30	2.21	.42	2.23	.70	100.70
1. Brazil													
2. Chesterfield	9.73	38.46	38.80	6.98	.....	.78	1.88	.72	2.47	.47	2.31	.55	100.55
3. Paris		38.47	40.93	2.77	.....	1.55	.88	1.21	1.47	.36			

Analysis by Cossu and Arzruni.

Ural	9.51	36.79	30.56	2.91	10.86	Cr ₂ O ₃	trace.	.72	.47	1.38	2.25	.62	100.08	3.07
------------	------	-------	-------	------	-------	--------------------------------------	--------	-----	-----	------	------	-----	--------	------

Rammelsberg concludes that all tourmalines can be referred to mixtures of the following silicate types: $R'_6\text{SiO}_5$, $R''_3\text{SiO}_5$, and $R'''_2\text{SiO}_5$, in which $R' = \text{H, K, Na, and Li}$; $R'' = \text{Mg, Fe, Ca, and Mn}$, and $R''' = \text{Al and B}$, making boric acid the equivalent of alumina. He groups them in two classes:

I. Magnesian-iron tourmaline, represented by the rather complicated formula

$$m \left\{ \frac{R'_6\text{SiO}_5}{3 R'''_2\text{SiO}_5} \right\} + n \left\{ \frac{R''_3\text{SiO}_5}{3 R'''_2\text{SiO}_5} \right\} \text{ where } R''' = \text{B} : 2 \text{ Al}$$

and

II. Lithia tourmaline, represented by

$$m \left\{ \frac{R'_6\text{SiO}_5}{8 R'''_2\text{SiO}_5} \right\} + n \left\{ \frac{R''_3\text{SiO}_5}{8 R'''_2\text{SiO}_5} \right\} \text{ where } R''' = \text{B} : 3 \text{ Al},$$

with the following special formulæ: $R'_2R''_2\text{Al}_4\text{B}_2\text{Si}_4\text{O}_{20}$ for the more purely magnesian varieties; $R'_{10}R''_4\text{Al}_{12}\text{B}_6\text{Si}_{12}\text{O}_{60}$ for the purer iron varieties, and for the lithia tourmaline $R'_6\text{Al}_{12}\text{B}_6\text{Si}_6\text{O}_{45}$, and other complications for those lithia varieties containing iron. The results may warrant these deductions; of that we have nothing to say. The important question concerns the chemical constitution of tourmaline. Attention has already been called to the weak points in Rammelsberg's analyses; but for the sake of emphasis I refer again to his method of determining the water percentages and what depends on it. He assumes that the fluorine is driven off quantitatively on ignition, carrying with it silicon as the tetra fluoride. This assumption is questionable. A half hour's blasting would seem to be sufficient to drive off the water, but it was repeatedly observed that where the tourmaline contained fluorine, further blasting, after the water was presumably all off, was invariably accompanied by a small loss of but a few hundredths per cent. This after loss is probably fluorine in some of its compounds with silica, as experiments made it clear that boric acid is not expelled by any amount of blasting. While making this correction for fluorine the oxidation of the iron is wholly ignored. With this in mind I have given loss on ignition in connection both with my own analyses and with those by Rammelsberg. Comparing this loss with the direct determinations of water, at the same time noting the amounts of iron contained in the respective tourmaline, one is forced to conclude that the oxidation of the iron plays an important rôle here in diminishing the loss on ignition by the amount required to convert it into ferric oxide. If we were to make the more justifiable correction for the oxidation of the iron, setting aside the fluorine correction, we would have more concordant results to deal with—results, moreover, which agree closely with the direct determinations of water—but if the percentages representing water are low, those of boric acid, when it is estimated by

difference, ought to be correspondingly high, and so they are in a few cases. In the greater number of analyses, however, they are unaccountably low, unless we suppose, as I am inclined to do, that the silica determinations run high, representing, in some cases, besides the actual silica, more than 1 per cent. of impurities. If all this be true, in working out his ratios Rammelsberg found in water and boric acid two variables instead of the two constants that they probably are.

It is scarcely necessary to say that certain constituents found in tourmalines are not essential, but have been thrust upon them by their associates. The idea that a tourmaline must contain fluorine was long ago exploded. Indeed, it had its birth not in facts but in Rammelsberg's assumption that tourmaline contained no water and that the loss on ignition was due wholly to fluorine.

Studying those constituents, which are the essentials, in the light of their molecular or atomic ratios, we find some very interesting relations. The ratios of certain elements are constants in all varieties of tourmaline. $\text{Si} : \text{B} : \text{H} : \text{O} = 1 : \frac{1}{2} : \frac{2}{3} : 5.2$. All the other constituents are variable within rather indefinite limits, and considered individually are confusing. If, however, the bases, including hydrogen, be reduced to a common univalent basis and be consolidated, the results fall into line with the above ratios. This reduction may be made in either one of two ways and with almost equally good results. It will be noticed that the oxygen ratio is invariably in excess of the amount necessary to the silicon and boron, even though we assume both the SiO_2 (as we certainly must) and BO_2 groups. This small residual is to be disposed of. It can be done by assuming the presence of either the $\text{Al}=\text{O}$ or the $\text{O}=\text{H}$ group. Both hypotheses have been made use of in the following table. $\text{R}^{(1)}$ is the univalent equivalent of the bases with the oxygen excess incorporated in an $\text{Al}=\text{O}$ group; $\text{R}^{(2)}$ the univalent equivalent of the bases on the basis of an assumed $\text{O}-\text{H}$ group. The table is given in full that the extent of the variations, from what seem to be simple ratios, may in no wise be concealed, as often happens, in giving averages. The hydrogen ratio, though already included in R , is given by itself, being one of the constants. For much the same reason the alkali ratios are also given, although with them the values vary according to the type of the tourmaline. This at least would appear to be true for the iron and lithia varieties.

	Si	B	$\text{R}^{(1)}$	$\text{R}^{(2)}$	O	H	Alk
Rumford A	1	.46	4.48	5.01	5.18	.74	.28
Brazil A	1	.47	4.45	5.12	5.26	.70	.31
Auburn A	1	.46	4.43	4.83	5.10	.72	.28
Brazil B	1	.47	4.50	4.92	5.17	.66	.31
Auburn B	1	.48	4.48	4.80	5.11	.71	.30
Brazil C	1	.45	4.42	4.93	5.15	.66	.32
Rumford B	1	.48	4.44	4.95	5.20	.64	.30
Auburn C	1	.46	4.50	4.99	5.20	.74	.28

	Si	B	R ⁽¹⁾	R ⁽²⁾	O	H	Alk
Paria.....	1	.45	4.47	5.09	5.21	.70	.12
Auburn D	1	.48	4.50	5.01	5.21	.70	.12
Brazil D	1	.48	4.50	5.02	5.21	.68	.13
Haddam.....	1	.50	4.51	5.00	5.24	.69	.12
Nantic Gulf	1	.51	4.52	5.00	5.25	.68	.12
Stony Point	1	.51	4.19	5.01	5.41	.68	.10
Pierrepont.....	1	.51	4.52	4.77	5.13	.63	.09
Monroe.....	1	.46	4.43	4.89	5.12	.69	.15
Orford	1	.48	4.48	4.99	5.20	.68	.13
Gouverneur	1	.50	4.51	4.73	5.10	.68	.10
Hamburgh	1	.51	4.50	5.08	5.30	.59	.06
De Kalb.....	1	.50	4.51	5.08	5.29	.66	.08
	1	.48	4.47	4.96	5.20	.67	
	1	$\frac{1}{2}$	$\frac{2}{3}$	5	$5\frac{1}{2}$	$\frac{1}{2}$	

Except in two or three cases the ratios of Si : B : R⁽¹⁾ : O approximate closely $1 : \frac{1}{2} : \frac{2}{3} : 5$, the oxygen, in excess of the amount exactly represented by the ratio (5), having been absorbed in an Al=O group. These ratios give as a general tourmaline formula the simple borosilicate $R_6BO_2SiO_4$. The R_6 includes the constant H= R_1 , (Li, Na, K) varying between the limits R_1 and R_3 , (Ca, Mg), varying from R_6 to R_7 , Fe varying from R_6 to R_1 , and (Al, Al=O) varying from R_4 to R_7 . On the other hand the ratio Si : B : R⁽²⁾ : O are about as $1 : \frac{1}{2} : 10 : 5.20$, which would give the equally simple general formula $R_{10}BO_2SiO_4$, when R_{10} includes the above constant and variables, excepting that OH replaces the Al=O group, and Al accordingly varies between the limits R_5 and R_6 . If we expand, in order to bring out the hydroxyl ratio, we have $12SiO_4, 6BO_2, R_{10}H_3(OH)_3 = Si : B : R : O = 1 : \frac{1}{2} : 5 : 5.25$. Between these two views there are no means at hand of deciding. Could we find that the water is not all driven off at the same temperature, or something of the kind, that knowledge would favor the latter assumption.

Experiments to this end are desirable; but whichever postulate we make, the following special formulæ may be taken as representing typical compounds of the three varieties:

I. Lithia tourmaline— $12 SiO_2, 3 B_2O_3, 4 H_2O, 8 Al_2O_3, 2 (NaLi)_2O$.

II. Iron tourmaline— $12 SiO_2, 3 B_2O_3, 4 H_2O, 7 Al_2O_3, 4 FeO, Na_2O$.

III. Magnesian tourmaline— $12 SiO_2, 3 B_2O_3, 4 H_2O, 5 Al_2O_3, \frac{2}{3} MgO, \frac{2}{3} Na_2O$.

Calculated.	I.	II.	III.
B ₂ O ₃	11.00	10.18	10.90
SiO ₂	37.70	34.89	37.38
Al ₂ O ₃	42.75	34.59	26.49
FeO .....	.....	13.95	.....
MgO .....	.....	.....	19.31
Li ₂ O	1.57	.....	.....
Na ₂ O	3.21	2.90	2.18
H ₂ O	3.77	3.49	3.74
	100.00	100.00	100.00

in comparing the theoretical composition of the above types with results of analysis, they will be found to agree as closely as could be expected, at least in the values of the constants. The boric acid invariably falls short of the theory. This is to be expected. The analyses do not represent ideal compounds, absolutely free from impurities, and the case would be very exceptional in which the impurities tended to raise and not to lower the percentage of boric acid.

In some of the above formulas the group BO_2 has been assumed because the oxygen ratio demanded it. As has already been suggested, the ease with which the iron oxidizes, and the mysterious manner in which this change takes place, under conditions where we would suppose it impossible, perhaps point toward a higher degree of oxidation than the more common B_2O_3 . As the result of a slow molecular rearrangement, the one is oxidized at the expense of the other. Such a change is, I believe, not without its analogies. Certain borates, where the assumption of an even higher oxide is thought necessary, on being heated, give borates of a lower order.

Notes.—The question of color is one of some consequence, particularly in the varying colors of the lithia tourmalines are concerned. For, as to the color of the iron and magnesian varieties depends on the amount of iron present, and ranges from the colorless De Kalb through the shades of brown to the Pierrepont black, the lithia tourmalines, containing more or less manganese, give us the red, green, and blue, as well as colorless varieties; the shades of color not depending on the absolute amount of manganese present, but rather on the ratios existing between that element and iron. When the ratios of $\text{Mn} : \text{Fe} =$ we have the colorless, pinkish, or very pale green tourmaline. An excess of manganese produces the red varieties. If, on the other hand, iron be in excess, the result is the various shades of green and blue. In a section of tourmaline showing a red center bordered by green, the two colors are usually separated by a narrow belt of nearly colorless material, in which the iron and the manganese are presumably in equilibrium.

As regards fusibility; the lithia tourmalines which are free from iron and magnesia are infusible. The presence of either or both of these elements brings with it a degree of fusibility increasing with their increase, till we find that the purest tourmalines, both iron and magnesian, fuse with great ease.

The titaniferous oxide associated with the Hamburg and De Kalb tourmalines attracted special attention because of its form. Having been examined chemically it was kindly studied microscopically by Mr. J. S. Newberry, who observed as follows:

Small iron black scales with a rather brilliant metallic luster are cleavable into thin foliae, the thinnest of which, under the microscope, are perfectly opaque. Reflected light these lamellae show three systems of cleavage planes, traces of which,

upon the plane of foliation, intersect at an angle of 60° . The cleavage planes make a large angle with the plane of foliation, and it is evident that this mineral is rhombohedral in crystallization. It is infusible on very thin edges, and does not become magnetic when heated. By this means it is distinguished from hematite and ilmenite. From its physical properties alone I should conclude that it is a member of the ilmenite series rich in oxide of titanium. As analysis shows it to be essentially titanio oxide, it becomes of special interest. In the first place it is the extreme member of the ilmenite series, and in the second place it is a new form of titanio oxide, which is thus shown to be tetramorphic.

NOTES ON CERTAIN RARE COPPER MINERALS FROM UTAH.¹

BY W. F. HILLEBRAND AND H. S. WASHINGTON.

Some time since analyses and partial descriptions of several rare copper minerals from the American Eagle Mine, Tintic district, Utah, were published² by one of us. These minerals had been found by Mr. Richard Pearce in ore shipments from that mine to the Boston and Colorado Smelting Works, near Denver, Colo. Later, in shipments from the neighboring Mammoth Mine, in the same district, Mr. Pearce discovered a second series of minerals of similar character, most of the species, however, being distinct from those of the former occurrence. In recent papers³ he has given the results of his examinations and enumerated the following species: Enargite, olivenite, conichaloite, clinoclasite, brochantite, pharmacosiderite, tyrolite (?), erinite, chalcophyllite, malachite, azurite, and one or two others of doubtful identity, of most of which "enargite is the mother mineral."

In order that this interesting series, in part new to America, might receive fuller study than he was able to devote to it, Mr. Pearce, with the assistance of Mr. Whitman Cross, selected a set of specimens for examination in the laboratory of the Geological Survey at Washington. The chemical work of this paper was there carried out by one of us,⁴ while the crystallographical and optical study was undertaken by the other,⁵ at New Haven, under the guidance of Prof. E. S. Dana. The results of our work, both chemical and physical, failed to meet some of the hopes induced by a first view of the material at disposal, although this was the best that could be found. They are of sufficient interest, however, to make public, especially in view of the meager state of our knowledge regarding a majority of the species herein mentioned.

¹ Read before the Colorado Scientific Society January 2, 1888, and published in the *Am. Journ. Sci.*, 3d series, vol. 35, 1888, p. 298.

² *Proc. Colorado Sci. Soc.*, vol 1, p. 112, and *Bull. U. S. Geol. Survey*, No. 20, p. 83.

³ *Proc. Colorado Sci Soc.*, vol. 2, pp. 134, 150.

⁴ W. F. Hillebrand.

⁵ H. S. Washington.

OLIVENITE.

This mineral occurred well crystallized. Its habit is tabular, parallel to a (100), and the crystals are, as usual, very simple, as shown in the figure. The planes b (010) and v (101) as a rule are either absent or very small. Measurements were made for the purpose of obtaining a more exact axial ratio than we have at present, the old values of Phillips dating back to 1823.

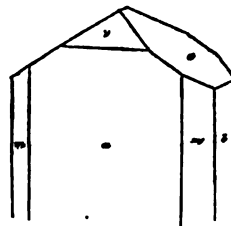


FIG. 1.—Crystalline form of olivenite.

Upon examination and measurement with a Fuess horizontal goniometer, it was found that $e \wedge \acute{e}$ (011 $\wedge$ 011) was the only angle sufficiently accurate for the purpose, a and m being a little rough and uneven. The angle mentioned furnished a good value for c , but to obtain the value for $\acute{a}$ use had to be made of a specimen of olivenite from the American Eagle Mine.¹ This olivenite was acicular in habit, the prism m (110) predominating. From these crystals good measurements were obtained of $m \wedge m'''$ (110 $\wedge$ 110), and a satisfactory axial ratio was deduced. The measured angles are as follows:

$$\begin{aligned} e \wedge \acute{e}, \quad 011 \wedge 0\bar{1}1 &= 67^\circ 51' \\ m \wedge m''', \quad 110 \wedge 1\bar{1}0 &= 86^\circ 26' \end{aligned}$$

From these angles we obtain the following axial ratio:

$$\acute{a} : b : c = 0.93961 : 1 : 0.672606$$

The measurements above differ considerably from the fundamental angles of Phillips, which are

$$e \wedge \acute{e}, \quad 011 \wedge 0\bar{1}1 = 69^\circ 10'$$

and

$$m \wedge m''', \quad 110 \wedge 1\bar{1}0 = 87^\circ 30',$$

giving the axial ratio

$$\acute{a} : b : c = 0.9573 : 1 : 0.6894.$$

Measurements were made with the view of determining whether the species is really orthorhombic or not. The following are the angles obtained:

$$\begin{aligned} a \wedge e, \quad 100 \wedge 011 &= 85^\circ 4', \quad \acute{a} \wedge e, \quad \bar{1}00 \wedge 011 = 89^\circ 59' \\ a \wedge \acute{e}, \quad 100 \wedge 0\bar{1}1 &= 89^\circ 9', \quad \acute{a} \wedge \acute{e}, \quad \bar{1}00 \wedge 0\bar{1}1 = 90^\circ 1' \end{aligned}$$

It is seen that the front angles are in each case a trifle less than the rear angles; but not much reliance can be placed on these results, owing to the poor surface of both a (100) and $\acute{a}$ ($\bar{1}00$).

¹ No. 5684 in the Yale collection.

Under the microscope the tabular crystals showed parallel extinction and a slight pleochroism, the vibrations $\parallel c$ being pale olive green, while those $\parallel b$ were of a brownish yellow, with the absorption $b > c$.

The mineral was not analyzed, because of the small quantity available, and because its identity was otherwise clearly established.

ERINITE.

Erinite occurs as a dark green crystalline lining of cavities, associated with and generally upon enargite, azurite, barite, or clinoclasite. Crystals of olivenite are frequently scattered over its surface, which shows often a somewhat satiny sheen due to minute crystal facets. Hardness 4.5, sp. gr. undetermined. Because of its intimate association with azurite and olivenite it was very difficult to obtain pure material for analysis. Sample I contained 3.90 per cent. of insoluble matter, not included in the analysis. Sample II was composed of a small lot of vitreous crusts, the only ones of the kind observed, which had been collected before shipment of the specimens, and were thought to be erinite by Mr. Pearce, whose partial analyses of material similar to sample I are added for comparison under III.

	I. Hillebrand.	II.	III. Pearce.	
			a.	b.
CuO.....	57.67 ¹	57.51	56.56	57.43
ZnO.....	1.06	0.59		
CaO.....	0.32	0.51	0.43	
MgO.....	trace	trace		
As ₂ O ₃	33.53	31.91	32.07	32.54
P ₂ O ₅	0.10			
H ₂ O.....	7.22	9.15	6.86	7.67
Fe ₂ O ₃	0.14	0.20	0.85	
SO ₃			trace.	
	100.04	99.87	96.77	97.64

Analyses I and II, and presumably those of Pearce, show the composition of air-dried powder. Sample I lost 0.67 per cent. H₂O over sulphuric acid and a total of 0.78 per cent. at 100° C. At 280° C. the total loss was 1.14 per cent., leaving 6.08 per cent. firmly combined. Sample II lost 2.06 per cent. over sulphuric acid and a total of 3.22 per cent. at 280° C., leaving 5.93 per cent. firmly combined. The molecular ratios, including all the water, are:

	CuO (CaO,ZnO).		As ₂ O ₃ (P ₂ O ₅).	H ₂ O.
I.....	5.08	:	1.00	: 2.74
II.....	5.34	:	1.00	: 3.66
III (mean).....	5.13	:	1.00	: 2.87

If the weakly combined water be excluded from both I and II, the ratio is brought considerably nearer to that derived from Turner's ap-

¹ Mean of 57.61 and 57.74.

proximative analysis,¹ i. e., 5 : 1 : 2. It is uncertain whether Turner's sample was air-dried or heated to 100° C.

TYROLITE (?).

Regarding the identity of this species some doubt exists, as the analytical results obtained do not agree with those given by von Kobell² and Church.³ In general appearance it seems to resemble tyrolite. It occurs in thin scales on quartz, but more often in radiating scaly masses, somewhat like the pyrophyllite from Graves Mountain, Georgia. It has a bright apple-green color, sometimes with a tinge of blue; a somewhat pearly luster; a hardness of 2.5 (1.5 to 2 for tyrolite in the text books), and perfect cleavage. Under the microscope it showed little or no pleochroism, and extinction parallel and perpendicular to the radial line. In convergent light the cleavage flake showed the ordinary biaxial figure with the dispersion $\rho > v$. Its double refraction is negative, the acute bisectrix being perpendicular to the cleavage face and coinciding with the crystallographic c . The obtuse bisectrix lies parallel to the radial direction of the crystal, but whether it corresponds with a or b can not be determined. It was unfortunate that a crystallographic investigation was impossible, as our knowledge of tyrolite in this respect is of the most meager description.

On heating it flies into fine fragments, which by gentle tapping of the tube collect into spongy masses. The mineral melts in the flame of a Bunsen burner. The sp. gr. of sample I (containing 2.25 per cent. of insoluble gangue) was 3.27 at 20½° C. From sample II, which was the purest and best crystallized to be found, 1.25 per cent. of gangue has been deducted.

	I.			II.	III.
	Hillebrand.				Pearce.
	<i>a</i>	<i>b</i>	Mean.		
CuO.....	45.20	45.23	45.22	46.38	42.60
ZnO.....	.....	0.04	0.04	trace	0.97 (Fe ₂ O ₃ , Al ₂ O ₃)
CaO.....	6.86	6.82	6.84	6.69	9.10
MgO.....	0.05	.....	0.05	0.04	.....
As ₂ O ₅	28.84	28.73	28.78	26.22	27.87
P ₂ O ₅	trace	.....	trace	trace	.....
H ₂ O.....	17.26	.....	17.26	17.57	16.23
SO ₃	(?)	(?)	(?)	2.27	2.45
	98.21		98.19	99.17	99.22

SO₃ was unfortunately not tested for in I. It may, however, reasonably be assumed to be present in about the same amount as in II, and

¹ Edinb. Journ. Sci., vol. 9, 1828, p. 95, and Phil. Mag., vol. 4, 1828, p. 154.

² Pogg. Ann., vol. 18, p. 253.

³ Journ. Chem. Soc., 2d series, vol. 11, p. 108.

if it be considered to be present as gypsum ($\text{CaSO}_4, 2\text{H}_2\text{O}$) the following molecular ratios are obtained:

	$\text{CuO}(\text{CaO})$.	As_2O_5 .	H_2O .		
I.....	5.00	: 0.94	: 6.80, or 11	: 2.07	: 14.96
II.....	5.00	: 0.84	: 6.81, or 11	: 1.85	: 14.98
III.....	5.00	: 0.90	: 6.29, or 11	: 1.98	: 13.84

It appears herefrom that the As_2O_5 is somewhat less and the H_2O much less than required to satisfy the formula $5\text{CuO}, \text{As}_2\text{O}_5, 9\text{H}_2\text{O}$, derived from von Kobell's (l. c.) analysis, on the supposition that the CaCO_3 found by him, and later by Frenzel¹ and church (l. c.), is not an essential constituent of tyrolite.

It is improbable that more than a very small quantity of chalcophyllite, if any, was mixed with the material analyzed under I and II, although both appeared on some of the specimens marked tyrolite received from Mr. Pearce, and are not always easily distinguished. In any mixture of tyrolite and chalcophyllite the water found must exceed its percentage in the former mineral. This is here not the case, whence it is to be inferred either that the present mineral is not tyrolite or that the older analyses do not represent its true composition.

A large portion of the water is very loosely combined. Of that in analysis I, 4.69 per cent. escaped at 100°C ., the most of it over sulphuric acid; and in analysis II, 4.15 per cent. was removed by sulphuric acid, and, further, 0.91 per cent. escaped at 100°C ., making a total of 5.06 per cent. These amounts, subtracted from the total percentage found, leave 12.57 and 12.51 per cent., respectively, or about five molecules (assuming five molecules $\text{CuO}(\text{CaO})$). At 280°C . the loss on sample II was 10.34 per cent., in which is presumably included the water of the gypsum supposed to be present, leaving three molecules firmly combined.

Church (l. c.) likewise noticed a great loss of water in vacuo and at 100°C ., but assumed that it was hygroscopic water included between the plates of the mineral. The second of his analyses, with data for calculating the centesimal composition, is as follows:

Substance.....	0.4585	CuO	50.06
H_2O in vacuo	0.024	As_2O_5	29.29
H_2O at 100°	0.011	H_2O	[8.73]
CaCO_3	0.0505	CaCO_3	11.92
CuO	0.212		
$\text{Mg}_3\text{P}_2\text{O}_7$	0.205		100.00

Whence he deduces the formula $5\text{CuO}, \text{As}_2\text{O}_5, 4\text{H}_2\text{O}$. Assuming that $\text{Mg}_3\text{P}_2\text{O}_7$ is an error for $\text{Mg}_2\text{As}_2\text{O}_7$, or for As_2S_3 , in which latter form it appears that arsenic was usually estimated by him in minerals of a similar character, it is impossible to deduce the above given percentage for As_2O_5 . But considering the latter correct, and including the water lost in vacuo and at 100° , the composition is:

¹ Naumann-Zirkel, Elemente der Mineralogie, p. 540.

CuO	46.24
As ₂ O ₅	27.05
H ₂ O	15.70
CaCO ₃	11.01
	100.00

which furnishes the molecular ratio CuO : As₂O₅ : H₂O as 5.00 : 1.01 : 7.43; not greatly differing from those derived from analyses I and II, above.

CHALCOPHYLLITE.

This mineral occurs in the form of small hexagonal plates arranged in rosettes, differing from the radial arrangement of the supposed tyrolite. It showed the same bright apple-green color, pearly luster, and perfect basal cleavage. An optical examination showed it to be uniaxial, with negative double refraction.

These crystals showed several planes replacing the edges, and measurements were made of them as far as possible. The angles did not agree very closely, owing to the imperfection of all the surfaces, but they were sufficiently exact to prove the presence of r (10 $\bar{1}$ 1, R), e (01 $\bar{1}$ 2, $-\frac{1}{2}$ R), and two other rhombohedrons new to the species, having the symbols w (1016, $-\frac{1}{3}$ R) and d (01 $\bar{1}$ 3, $-\frac{1}{3}$ R).

The figure shows the habit of the crystals; but with d absent, this plane being only observed in one instance. The very rough angles obtained are given below:



FIG. 2.—Crystalline form of chalcophyllite.

	Observed.	Calculated.
cAr , 0001 $\wedge$ 10 $\bar{1}$ 1 =	71° 27'	71° 16'
cAw , 0001 $\wedge$ 00 $\bar{1}$ 6 =	26° 10'	26° 10' 20"
cAe , 0001 $\wedge$ 01 $\bar{1}$ 2 =	56° 51'	55° 51' 10"
cAd , 0001 $\wedge$ 01 $\bar{1}$ 3 =	41° 50'	44° 30' 30"

The above angles are the means of several measurements, which vary among themselves from one to three degrees. The fair agreement in the first two results therefore is merely accidental, and no value can be attached to these measurements, which are inserted because the measurements of this species are extremely few.

The mineral was not analyzed, for want of sufficient material. On heating it decrepitated as violently as the last-mentioned mineral, and in the flame of the burner fused, though not with the same readiness.

CLINOCLASITE.

The clinoclasite occurs in two distinct habits—one distinctly crystallized and the other in barrel-shaped or globular forms. It is of a dark bluish green color, almost black by reflected light, bright green by transmitted light. Streak and powder bluish green. Sp.

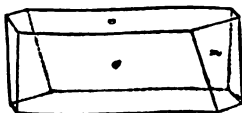


FIG. 3.—Crystalline form of clinoclasite.

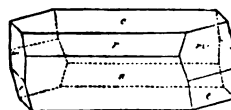


FIG. 4.—Crystalline form of clinoclasite.

gr. at 19° C. 4.38 (4.36 Pearce). Hardness, 2.5 to 3.

At first sight these crystals seemed to be very promising and likely to afford good measurements for the species. But on further examination they did not come up to our expectations, c (001) and s ($\bar{3}02$) being the only two faces giving even fairly good measurements. m (110), r (101), t ($\bar{1}11$), and p ($\bar{1}13$), the other planes observed, were all dull or rounded, and only capable of giving angles accurate enough to identify the forms. Of the planes above, t and p are new to the species. Most of the crystals were apparently made up of two or more individuals in nearly parallel position, but inclined slightly in the zone c/b .

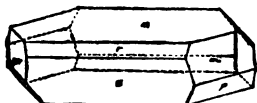


FIG. 5.—Crystalline form of clinoclase.

A measurement in one case gave the angle $4^\circ 10'$, but as it is not the result of twinning this angle of course is not constant, and only shows the very slight inclination of the individual crystals. A consequence of this method of growth will be described later.

The crystals were all simple, the form in Fig. 3, or a combination of that with r being the most usual. Occasionally the lower half of m is replaced by t , as shown in Fig. 4, giving the angle $13^\circ 20'$ (calculated $13^\circ 17'$) for $m \wedge t$. The new plane p ($\bar{1}13$) was observed in several crystals and is shown in Fig. 5.

The following angles were obtained for it:

	Observed.	Calculated.
$c \wedge p$, $001 \wedge \bar{1}13$	$= 61^\circ 6'$	$61^\circ 26' 30''$
$s \wedge p$, $\bar{3}02 \wedge \bar{1}13$	$= 50^\circ 14'$	$51^\circ 19' 10''$
$p \wedge p'$, $\bar{1}13 \wedge \bar{1}\bar{1}3$	$= 82^\circ$	$85^\circ 48'$

The angles are merely approximate, but sufficient to establish the form. The crystals are for the most part elongated in the direction of the b axis, with a length of from 2 to 3 millimeters, and show easy cleavage parallel to c .

The other type of clinoclase is interesting as showing the consequence of the nearly parallel growth of the crystals mentioned above. In some of the specimens the crystals are grouped about the b axis, with c exposed. They are inclined a trifle in the zone c/b and also in the zone a/b , thus rounding off the group in two directions, but decidedly more in the latter zone, forming, with the elongation in the direction of b , distinctly barrel-shaped forms. Occasionally the curvature in the zone c/b is carried still further, producing globular forms. In all cases c forms the outer surface and the crystals are closely crowded together, producing a bright and coarsely rough surface.

The material analyzed consisted of the globular masses mentioned above, and was probably not as pure as the crystals and barrel-shaped forms. A trifling amount of insoluble matter (0.05 per cent.) has been deducted. For comparison, Mr. Pearce's partial analyses are also quoted.

	I. Hillebrand.			II. Pearce.		Theoretical composition.
	a	b	Mean.	a	b	
CuO	62.34	62.54	62.44	61.68	61.22	62.65
ZnO	0.06	0.04	0.05			
As ₂ O ₃	29.59	29.60	29.59	29.36	28.85	30.25
P ₂ O ₅	0.05	0.05*	0.05			
H ₂ O	7.73	7.72	7.72	7.31	7.27	7.10
Fe ₂ O ₃	0.12	0.12	0.12			
SiO ₂	0.06	0.06*	0.06			
	99.95	100.13	100.03	98.35	97.34	100.00

* Assumed the same as in a.

These results reveal nothing worthy of remark, except that the water, as in most earlier analyses, is found uniformly higher than that required by the formula 6CuO , As_2O_3 , $3\text{H}_2\text{O}$, or $\text{Cu}^3 [\text{AsO}_4]^{12} + 3\text{Cu} [\text{OH}]^{12}$.

MIXITE (?).

On some specimens of ore, but apparently not in close association with the other minerals mentioned, was a mineral occurring in delicate tufts of silky needles of a whitish to pale greenish color, as described by Mr. Pearce.¹

It was impossible to procure enough of the needles free from an underlying non-crystallized greenish coating of cavities for a satisfactory analysis. A good deal of the latter was necessarily included in the sample tested, but qualitative tests showed that both needles and coatings contained the same constituents. It is hardly to be doubted that both have the same centesimal composition.

	I. Hillebrand.			II. Pearce.
	a	b	Mean.	
CuO	43.89	43.88	43.89	50.50
ZnO	2.79	2.62	2.70	
CaO	0.26	0.26	0.26	3.19
Bi ₂ O ₃	11.14	11.22	11.18	
As ₂ O ₃	27.78	28.79	28.79†	27.50
P ₂ O ₅	0.06		0.06	
H ₂ O	11.04	11.04	11.04	12.55
SiO ₂	0.36	0.48	0.42	
Fe ₂ O ₃	0.97		0.97	
	98.29		99.31	93.74

† The higher value was undoubtedly nearer the truth than the lower.

That an error as to the CuO occurs in Pearce's analysis is beyond question. The above results agree fairly well with Schrauf's analysis of mixite,² which contained 43.21 CuO, 13.07 Bi₂O₃, 30.45 As₂O₃, and 11.07 H₂O, besides a little CaO and FeO; but the form of this mineral was given by Schrauf differs from that of the present one, and its colors given as emerald to bluish green. Schrauf's number for the specific

¹ Proc. Colorado Sci. Soc., vol. 2, p. 151, under the title "New Mineral."² Zeit. f. Kryst., vol. 4, p. 277.

gravity (2.66) is unquestionably much too low. That of the material now analyzed was 5.79 at $23\frac{1}{2}^{\circ}\text{C}$. When treated with dilute nitric acid it becomes at once covered with the brilliant white coating of bismuth arseniate, so characteristic of mixite. The latter mineral is stated to belong to the monoclinic or the triclinic system, while the observations of Mr. Whitman Cross would indicate that the present one can belong to neither of those systems. He says:¹ "The needles are very slender, with a length of more than 1^{mm} in some cases, by a thickness of less than 0.05^{mm}. They are deeply striated vertically, and the crystal system could not be determined, although the extinction in polarized light makes reference to the tetragonal; the hexagonal, or the rhombic system necessary. The index of refraction is high. Pleochroism distinct—the colors observed being for the thicker crystals, *a* (and *b*) sea green = *c* sky blue."

PHARMACOSIDERITE.

For want of sufficient material no analyses were made.

BROCHANTITE.



FIG. 6.—Crystal-line form of brochantite.

This hydrous sulphate of copper occurs in two distinct types in the specimens examined. The first, or ordinary brochantite, is of a prismatic habit, as is shown in Fig. 6. The crystals are dark green and transparent, but do not give good measurements, owing to the imperfection of the surface. The cleavage parallel to *b* (010) is perfect. The measured angle of $m \wedge b$ ($110 \wedge 010$) = $51^{\circ} 46'$ is only approximate, and differs considerably from Miller, who gives $52^{\circ} 5'$, and Schrauf, who gives 52° .

The second type is like Waringtonite from Cornwall, described by Maskelyne.² This variety was suspected by Mr. Pearce (*loc. cit.*, p. 135). It is of a light green color, and has a curved double-wedge-shaped habit. The forms observed are shown in Figs. 7 and 8. The crystals were poor for measuring, all the planes, with the exception of *b*, being curved to a great degree. The crystals were none of them



FIG. 7.—Crystalline form of brochantite.

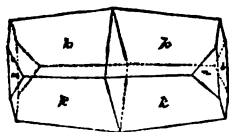


FIG. 8.—Crystalline form of brochantite.

more than two or three millimeters long, with the relative proportions of the figures. They were implanted by *b*. *m*, in Fig. 8, was identified with certainty; the angle for $b \wedge m$ being 52° approximately. The plane lettered *k* was very much curved in all cases, and its symbol, consequently, is not known with exactness. It corresponds in its angles, very roughly, it is true, to the *k*, 12. 1. 4

¹ Proc. Colorado Sci. Soc., vol. 2, p. 153.

² Chem. News, vol. 10, p. 263, 1864, and Phil. Mag., ser. 4, vol. 29, p. 475,

of Schrauf, some of the angles obtained from these crystals and the corresponding ones of Schrauf's Waringtonite being given here:

	Washington.	Schrauf.
$b \wedge k, 010$	$\wedge 12.1.4 = 80^{\circ}-82^{\circ}$	$86^{\circ} 43'$
$m \wedge k, 110$	$\wedge 12.1.4 = 45^{\circ}$	$43^{\circ} 11'$
$k \wedge k', 12.1.4$	$\wedge 12.1.4 = 75^{\circ}-80^{\circ}$	

In most of the crystals of this type b was undulating parallel to c .

Want of material forbade an analysis of this mineral, but blow-pipe tests and the crystallographic examination establish its identity beyond doubt.

MINERALOGICAL NOTES.¹

By W. F. HILLEBRAND.

Although the results of analysis of the herein-mentioned minerals, unsupported as they are, with one exception, by any crystallographic evidence, lead to complete identification of the species only in one case, they are deemed of sufficient importance to place on record, together with such information regarding their physical properties as could be gathered from the material at hand, which was in some cases rather scanty.

A few years ago in granitic débris on Devil's Head Mountain = Douglas County, Colo., in the Pike's Peak region, Mr. W. B. Smith found a number of minerals which appeared worthy of examination. Two of these, allanite and gadolinite, have already been analyzed by Mr. L. G. Eakins.² The following analyses, I-VI, represent the composition of the others, of which all but No. III were made in the laboratory of the U. S. Geological Survey, in Denver, over two years ago.

1. SAMARSKITE ?

The mineral first to be mentioned occurred in fragments of all sizes up to that of a chestnut, without any evidence of crystal form except on a small portion of one piece, where a structure resembling that shown in Fig. 9 was apparent. The color was pitch black, with brilliant vitreous luster, but pale brown in thin splinters; streak dirty brown. The pieces were very brittle, and when heated flew into fine, sharp fragments. Fracture subconchoidal. These characteristics agree very closely with those given by J. Lawrence Smith³ for the purest North Carolina samarskite, but the density is much greater, being 6.18 at 22° C. for I, as might be expected from the percentage of Ta₂O₅, which is much higher than that as yet found in any recognized samarskite. Hardness, 5.5 to 6. Slight solubility in HCl was shown on prolonged boiling, and a somewhat greater in H₂SO₄. Before the blow-pipe a splinter became dull, but did not fuse. Analysis I shows the composition.



FIG. 9.—Samarskite (I).

A single piece of but a few grammes weight, while in its general behavior and appearance resembling those just described, presented two points of difference. The streak was salmon colored, and the rather thin piece was bounded on two opposed sides by flat surfaces, which

¹ Read in part before the Colorado Scientific Society, March 5, 1888.

² Proc. Colorado Sci. Soc., vol. 2, p. 32.

³ Am. Jour. Sci., 3d series, vol. 13, 1877, p. 359; Ann. Chim., vol. 12, 1877, p. 253; Original Researches in Mineralogy and Chemistry, p. 197.

might possibly be the result of cleavage. These observed differences led to analysis II. The density at 25° C. was 6.12, and the hardness 5.5. As the analysis reveals a remarkable agreement in composition with the first-described specimens, there is no reason to suspect the presence of distinct species.

Analysis III gives the composition of the specimen shown in Fig. 9, which it was thought might be an altered state of the above-described mineral. It was evidently in an advanced stage of alteration, being very easily broken, and so much stained (brown) that scarcely any evidence of its original color and luster could be observed, though what little of these features remained indicated agreement with those above mentioned. As some water escaped at 100° C., and still more for each further slight increase in temperature, air-dried material was taken for the analysis. This shows in most respects so close an agreement with I and II, that the assumption of original identity with the brilliant black mineral does not seem far-fetched. The chief differences lie in the much lower percentage of Ta_2O_5 in III, and the presence of UO_3 instead of UO_2 . The density at 16° C. was 5.45.

Analyses of samarskite.

	I.	II.	III.
Ta_2O_5	27.03	28.11	19.34
Cl_2O_5	27.77	26.16	27.56
WO_3	2.25	2.08	5.51
SnO_2	0.95	1.09	0.82
ZrO_2	*2.29	*2.60	3.10 (with TiO_2)
UO_3	4.02	4.22	6.20 (UO_3)
ThO_3	3.64	3.60	3.19
Ce_2O_3	0.54	0.49	0.41
$(Di, La)_2O_3$..	1.80	2.12	1.44
Er_2O_3	†10.71	†10.70	†9.82
Y_2O_3	†6.41	†5.96	†5.64
Fe_2O_3	8.77	8.72	8.90
FeO	0.32	0.35	0.39 (or 0.74 UO_3)
MnO	0.78	0.75	} 0.77
ZnO	0.05	0.07	
PbO	0.72	0.80	1.07
CaO	0.27	0.33	1.61
MgO			0.11
K_2O	0.17	0.13	} 0.36
$(Na, Li)_2O$..	0.24	0.17	
H_2O	1.58	1.30	3.94
Fl	†	†	†
	100.31	99.75	100.18

* Probably containing some TiO_2 .

† Calculated from the molecular weight of the mixed oxides of this group on the unsupported assumption that only Er_2O_3 and Y_2O_3 were present. The molecular weight in the case of I was 304.9; in that of II, 307.7.

The method of analysis followed was, with certain modifications, that devised by J. Lawrence Smith.¹ Two instead of five grammes of material were taken for greater convenience in manipulation.

A few remarks in regard to certain points in the course of analysis may prove of service to those having similar analyses to make. By the method of Smith the constituents of the mineral are divided at once into two portions, those soluble in HFl and those insoluble. The former portion includes Ta, Ob, Sn, W, U (if present as UO_2), Fe,² Ti, Zr in part, Zn, Mn, Mg, K, and Na, while the latter contains the earths of the cerium and yttrium groups, Th, U (if present as UO_2), part of the Zr when other earths are present, a small part of the Fe, and the Pb and Ca.

It was found, after converting the insoluble fluorides into sulphates and dissolving in water, that a white insoluble residue remained, which, according to Smith in the case of samarskite, should be Ob_2O_5 and Ta_2O_5 . Neither of these could be found in it, however, the whole being lead sulphate. After filtering, the remainder of the lead was thrown down by H_2S . The uranium then having been oxidized by nitric acid, the earths (except ZrO_2 and some CaO) were thrown down by oxalic acid (not ammonium oxalate) in excess. The use of oxalic acid was rendered necessary by the observed solubility of the earths of the yttrium group in ammonium oxalate. These when freed from bases of the cerium group were not precipitated by this reagent, or, more properly, the precipitate at first formed dissolved *completely* in excess of the precipitant on very gentle warming and was not again precipitated on cooling. This behavior indicates the presence of erbium in quantity, which may influence the yttrium present, for the latter by itself is stated to be only partially soluble in concentrated boiling ammonium oxalate and to be again thrown out on cooling. It should be remarked, however, that the solubility above mentioned was very much greater than when to a hot solution of erbium and yttrium sulphates,³ prepared according to the data furnished by the above analyses, ammonium oxalate was added in excess.

The filtrate from the insoluble fluorides was evaporated to dryness, dissolved in water and a few drops of HFl, and the tin was thrown down by H_2S , as done by Marignac.⁴ The filtrate was then evaporated with large excess of H_2SO_4 , heated till all HFl was certainly removed;

¹Am. Chem. Journ., vol. 5, pp. 44, 73; Chem. News, vol. 48, pp. 13, 29; Original Researches in Mineralogy and Chemistry, p. 350.

²Treatment with HFl at once reveals whether the iron is present as admixed hematite or limonite (as in analysis III, where it remained suspended in the liquid in an extremely fine state of division), or is chemically combined with the acids of the mineral. In the first case it resists the solvent action of HFl for some time after the tantalates and columbates are thoroughly decomposed.

³From T. Schuchhardt. Though marked *chem. pure*, it is not at all probable that they were so.

⁴Ann. Ch. Phys., 4th series, vol. 13, p. 5.

then, without driving off the excess of H_2SO_4 , diluted and boiled (stirring constantly to prevent bumping) in a very large platinum dish for ten or fifteen minutes. The precipitate collected on a filter was then dissolved in HCl , the filtrate evaporated with excess of H_2SO_4 and treated in every way as above described till after the third precipitation by boiling. The combined filtrates were then evaporated, most of the H_2SO_4 was driven off, the residue taken up with water and boiled for some time. The remainder of the metallic acids, except some TiO_2 , if present, is now entirely precipitated, but to free altogether from ZrO_2 , Fe_2O_3 , and from most of the TiO_2 the precipitate was again dissolved in HCl , the filtrate was evaporated with H_2SO_4 , the excess of the latter partly driven off, and the acids were again thrown down by boiling.

This process is somewhat tedious, but seemed to possess the advantage of entirely separating Ta, Cb, and W from Fe and Zr and in great measure from Ti, unless the latter is present in quantity. The point to be observed is that the first precipitations shall be made in strongly acid solutions, the latter in solutions less strong. The procedure of Smith—driving off nearly all H_2SO_4 at first and then boiling with HCl —is objectionable; the metallic acids become strongly caked during removal of the H_2SO_4 and retain much iron, which no amount of boiling with HCl can remove. The further treatment of the combined filtrates requires no special mention.

For the separation of WO_3 the ignited and weighed oxides were fused with Na_2CO_3 and S and separated as recommended by Rose. The method, however, leaves much to be desired, for a considerable quantity of the B_2O_3 acids goes into solution with the W. Cb_2O_5 , and Ta_2O_5 were separated by Marignac's method.

FeO was estimated by titration with KMnO_4 after solution of the very finely powdered mineral in H_2SO_4 by heating for two or three days in sealed tubes, a blank experiment being made with H_2SO_4 alone in another tube. The excess of KMnO_4 above that required for the conversion of all uranium (when assumed present as UO_2) to UO_3 was considered to be equivalent to the FeO . The accuracy of the determination is of course not affected by the fact that uranous salts reduce ferric salts in solution.

Fluorine could not be found quantitatively, but from the slightly acid reaction of the water evolved on heating the mineral, its presence is rendered probable.

From the two first analyses it is impossible to identify the mineral with any known species beyond doubt, although it appears to be more nearly allied to samarskite than to any other. The presence of the iron as Fe_2O_3 distinguishes it from most other tantalates and columbates containing much iron. That the greater part of the iron exists in the ferric condition is certain, for if the uranium existed as UO_3 instead of UO_2 , as assumed, the amount of KMnO_4 required to oxidize 4.02 per cent. of UO_3 (anal. J) would indicate but 2.13 per cent. of FeO .

2. AN ILL-DEFINED ZIRCONIUM MINERAL.

With the mineral just described occurred peculiar growths, from an inch to an inch and three-quarters in length, of a pale brown color, and having the forms shown in Figs. 10 and 11, of which analyses IV-VI represent the composition. Evidences of crystal faces were observed on the upper terminations of some specimens. It seemed not at all probable from its appearance that the substance was homogeneous, and a thin section showed plainly a mixture of two or more minerals. One of these is probably limonite, and the action of HFl supports this view; for, while the powder as a whole was instantly decomposed, brown oxide of iron remained for some time suspended in the liquid.



FIG. 10.—Cyrtolite (?).



FIG. 11.—Crytolite (?). The specimen represented by analysis VI differed much in appearance in places from the others, fractured surfaces being coarsely granular, and showing clear reddish grains of some size which could easily be detached. The sp. grs. were 3.70 (IV), 3.60 (V), 3.64 (VI): The analyses give the composition of air-dried material, for it was found that at 100° C. and with each further increase in temperature water was lost. They are only of value as showing the composition of these characteristic forms, which are mixtures of perhaps cyrtolite, or some allied alteration product of zircon, with limonite and a phosphate.

Analyses.

	IV.	V.	VI.
Ta ₂ O ₅	47.99	0.71	51.00
SnO ₂		0.03	
ZrO ₂		47.81	
SiO ₂	20.06	20.64	19.21
ThO ₂	1.16	1.20	0.60
Ce ₂ O ₃	0.06		
(Di,La) ₂ O ₃	0.19		
Er ₂ O ₃	4.77	4.76	4.55
Y ₂ O ₃	2.27	2.48	3.13
Fe ₂ O ₃	5.53	5.97	4.86
MnO	0.47	0.57	0.33
CaO	1.99	1.93	2.15
MgO	0.13	0.11	.....
K ₂ O	0.20	0.10	0.17
Na ₂ O	0.46	0.50	0.42
H ₂ O	12.87	12.00	12.97
P ₂ O ₅	1.64	1.75	0.93
Fl	0.25	0.42	0.42
	100.04	100.98	100.74

3. WHITE BERYL.

The crystals analyzed were from a specimen in the National Museum found in a tin mine near Winslow, Me. The beryl is of interest on account of its color, which is white, with a faint greenish hue under certain conditions of light. Mr. J. S. Diller examined the crystals and reported as follows:

The white beryl which you gave me to examine is full of gas and liquid inclusions, most probably air and water, to which the light color of the beryl is due. Besides these it contains a considerable amount of fine ferritic dust, but on the whole is about as pure as minerals usually are. The beryl itself is fresh, and has suffered but little, if any, alteration.

The sp. gr. at 27°C. was 2.707.

VII.

SiO ₂	65.21	K ₂ O }	0.14
TiO ₂	trace	Ca ₂ O }	
Al ₂ O ₃	18.50	Na ₂ O	0.87
Fe ₂ O ₃	*0.33	Li ₂ O	0.16
BeO	†13.03	H ₂ O	‡1.80
MgO	0.09	P ₂ O ₅	none

100.13

*FeO, if present, not estimated.

†BeO and Al₂O₃ separated in the manner described by Penfield. (Am. Jour. Sci. [3], xxxii, 114).

‡After drying at 110° C.

4. A SULPHIDE OF COPPER, SILVER, AND ZINC.

Mr. Richard Pearce gives an analysis¹ of a mineral from the Gagnon Mine, Butte, Mont., which he describes as massive, and in appearance much like bornite, with density 4.95 and hardness 3.5 to 4. A specimen received from Mr. Pearce, and analyzed at his request, had a density of 5.407 at 20° C. It was rather brittle, but flattened out in part under the pestle. From analysis VIII 0.12 per cent. of gangue has been deducted. Pearce's analysis is given under IX.

	VIII.	IX (Pearce.)
Cu	40.24	41.10
Ag	21.80	24.66
Pb	1.46	.....
Zn	12.83	9.80
Fe	1.98	2.09
S	20.88	20.51
Insoluble .....	.....	1.02
	99.19	99.18

¹Proc. Colorado Sci. Soc., vol. 2, p. 70.

The general formula deduced from both analyses is RS , with the different constituents apparently in varying proportions. It is impossible from the specimens examined to decide whether the mineral is new or only a mixture.

5. AN ARGENTIFEROUS ARSENIDE OF NICKEL AND COBALT.

From Mr. W. George Waring, through Mr. Whitman Cross, a mineral from the Rose Mine, Grant County, N. Mex., was received, which has the composition given under X. It is said to occur also in the Black Hawk Mine, in the same county. It has a steel-gray color, and the particles abraded by a sharp blow of the hammer "take fire, and the pathway of each particle thus ignited as it falls to the ground is marked very distinctly by a trail of dense, white smoke," according to Waring. In a closed tube a heavy sublimate of arsenic is formed on very moderate heating. The gangue of the mineral is mainly carbonate of lime and iron with quartz. The carbonates may be extracted with HCl , when the arsenide is left entirely unaffected and showing evidences of crystalline structure ("pyritohedral," Waring). The sp. gr., after correcting for 4.80 per cent. of quartz, was 6.644 at $20^{\circ} C$.

	X.		X.
As	74.04	Ni }	*19.52
S	0.13	Co }	
Ag	4.78	CaO	0.09
Cu	0.04	MgO	0.05
Pb	0.03		99.12
Fe	0.44		

* The separation of Ni and Co miscarried. According to a blow-pipe analysis by Waring the proportion of Ni to Co is as 3 to 1.

The atomic ratio of Ni, Co, Ag, Fe to As is much above 1: 2.5, showing either that the substance is a mixture of two minerals with the general formulas RAs_2 and RAs_3 , or of arsenic with one of the formula RAs_2 .

6. A BASIC CUPRIC SULPHATE.

Two soft lumps of ore of a light green color (rubbing off on the fingers) from the Antler mine, Yucca Station, on the Atlantic and Pacific Railroad, in Mohave County, Ariz., gave the following composition, after deducting 8 and 6 per cent. respectively of gangue, which latter consisted mainly of quartz and a brownish foliaceous mineral. Sp. gr. at $16^{\circ} C$., 3.93, after correcting for gangue, the density of which was assumed to be 2.6.

	XI.	XII.
CuO.....	68.19	67.64
ZnO.....	0.29	0.04
CaO.....	0.05	0.04
SO ₃	20.46	21.49
H ₂ O.....	11.11	10.76
	100.10	99.97

The molecular ratios are:

	RO	SO ₃	H ₂ O
I	10.00	: 2.98	: 7.19
II	10.00	: 3.15	: 7.01

which lead to the formula $3\text{CuSO}_4 + 7\text{Cu}[\text{OH}]_2$, for which theory requires 68.45 CuO, 20.69 SO₃, 10.86 H₂O. If in time this should prove to be a well-defined species, which conclusion the absence of crystalline form and want of very close agreement in the analyses do not warrant at present, the name *antlerite*, from the mine in which it occurs, is suggested as appropriate.

ANALYSES OF NATURAL BORATES AND BOROSILICATES.

BY J. EDWARD WHITFIELD.

Most of the published analyses of natural borates have the boric acid determined either by difference or by some of the methods which have been shown to be inaccurate, and they are therefore subject to question as to the exact ratios and formulas. A method for the direct estimation of boric acid having been devised in this laboratory by Dr. F. A. Gooch,¹ it was thought advisable to repeat the analyses of a few of the borates, and verify, if possible, the given formulas or correct errors caused by defective analytical methods. With this object in view, the following analyses were undertaken.

The methods employed differ in many cases from those used by other analysts in the already published accounts of these minerals. In the estimation of the ferrous iron, the method employed was to decompose the finely ground mineral with hydrofluoric and hydrochloric acids in an atmosphere of carbonic acid, and heating to a temperature of about 100° C. in a tightly sealed platinum vessel, devised and used expressly for such determinations, and when thoroughly decomposed—which is generally the case after standing twelve hours, with occasional shaking—to titrate with permanganate of potassium. This method is undoubtedly superior to that employed by Rammelsberg and Tschermak in their analyses.

The direct estimation of the water was made, after drying the mineral at 104° C., with the apparatus devised by Dr. Gooch,² by which the error caused by calculating the water from ignition and ignoring the oxidation of the ferrous iron is eliminated.

The silica in every case has been corrected by evaporation with hydrofluoric and sulphuric acids, and the residue added to the precipitate of iron and alumina.

COLEMANITE, FROM DEATH VALLEY, CALIFORNIA.

Of this mineral there was put at my disposal two specimens very different in appearance. One, designated as A, was a large, transparent crystal of the ordinary type, to all appearances perfectly clear and free from impurities.

¹ Bulletin U. S. Geological Survey, No. 42, p. 647.

² Am. Chem. Jour., vol. 2, 1880, p. 247.

By analysis the following results were obtained, and I insert for comparison the analysis by Mr. J. T. Evans¹ and the theoretical composition calculated from the formulas given below:

	A.	J. T. Evans.	Theory.
H ₂ O	= 21.87	= 21.835	= 21.9
B ₂ O ₃	= 50.70	= 50.990	= 50.9
CaO	= 27.31	= 27.175	= 27.2
MgO	= .10	=	=
	99.98	100.000	100.0

The molecular ratios from analysis A are CaO : B₂O₃ : H₂O—2 : 3 : 5, resulting in the simple formula 2CaO, 3B₂O₃, 5H₂O, the calculated composition of which does not differ much from the results of the analysis. Mr. Evans calculated the same formula from his analysis, in which the boric acid was determined by difference.

The second specimen, B, was from the same locality, but was in the form of a deposit, implanted on gangue, and consisted of small blade-like crystals, almost white, but in some lights appearing of a greenish cast.

By duplicate analyses the following results were obtained:

B.		
H ₂ O	22.66	22.70
B ₂ O ₃	49.56	49.62
CaO	27.36	27.40
MgO	.25	.26
SiO ₂	.44	.47
	100.27	100.45

These results prove the mineral to be the same as variety A, but containing very slight impurities. The difference in the general appearance of the two specimens suggested a crystallographic examination of variety B; and, through the kindness of Prof. E. S. Dana, the following description was furnished by Mr. H. S. Washington, of New Haven:

The white transparent crystals, of about 2 to 5^{mm} in length, occur implanted on a light porous gangue, either in parallel position or in rosette-like aggregations, overlapping one another like shingles on a roof. They have in several places implanted on them small, white opaque, spheroidal masses, presumably of priceite. The habit of the crystals is remarkable, being unlike almost all the forms of colemanite previously described. Prof. A. W. Jackson² gives one figure resembling these forms, though more complex. They look at first sight like two rhombohedræ of calcite; the combination of prism and ortho-dome giving the mineral a decidedly rhombohedral aspect, as shown in Figs. 12, 13.



Fig. 12.—Crystalline form of colemanite.



Fig. 13.—Crystalline form of colemanite.

¹Proc. Cal. Acad. Sci., No. 1; Neues. Jahr., 1886, 1-1-37.

²Bull. Cal. Acad., No. 4, pp. 358-374, plates.

None of the crystals examined admitted of good measurements, the faces being broken, rough, or curved. They were accurate enough, however, for determining the symbols. The plane W 301 was curved very conspicuously and regularly, the face having, near a 100, the position approximately represented by the symbol 501. This habit was very constant, the prism m 110 and orthodome W 301 being the only planes observed, with the exception of b 010, produced by the perfect cleavage, and a small and very uncertain plane observed in one or two cases replacing the edge W 301 $/m'$ 110.

PRICEITE, FROM CURRY COUNTY, OREGON.

The specimen examined was white and chalky, and proved to be very pure material. An analysis gave the following composition, and I copy the results of an analysis by Silliman¹ and another by Mr. Thomas Price² for comparison:

	Whitfield.	Silliman.	Price.
H ₂ O	19.42	18.29	22.75
B ₂ O ₃	48.44	49.00	47.04
CaO	32.15	31.83	29.98
NaCl, Fe ₂ O ₃ , Al ₂ O ₃		.96	.25
	100.01	100.08	100.00

The ratios from my figures are CaO: B₂O₃: H₂O—19: 23: 36, which do not conform to any simple formula. In both the earlier analyses the boric acid was determined by difference, and there is a discrepancy between them of about 2 per cent.

PANDERMITE, FROM THE ISLAND OF PANDERMA, IN THE BLACK SEA.

The material was hard and compact, somewhat resembling marble.

H ₂ O	19.40
B ₂ O ₃	48.63
CaO	32.16
	100.19

From these figures it will be seen that the priceite and the pandermite are in composition identical, the difference being wholly in the physical appearance of the material. The priceite is soft and friable, while the pandermite is compact. From the results obtained it is apparent that they are the same mineral.³

CLEIXITE, FROM RHODES' MARSH, ESMERALDA COUNTY, NEVADA.

The material for analysis was taken from one of the nodules found in this locality, which on being broken exposed the fine, silky fibers characteristic of the mineral.

¹ Am. Jour. Sci., ser. 3, vol. 6, pp. 128-130.

² Am. Jour. Sci., ser. 3, vol. 5, pp. 287-290.

³ Dana, Syst. Min., app. III-97.

An analysis gave the following figures :

	Found.	Calculated.
SiO ₂	0.04	.....
Cl.....	2.38	.....
B ₂ O ₃	43.20	45.34
SO ₃	0.28	.....
CaO.....	14.52	15.04
Na ₂ O.....	10.20	8.83
K ₂ O.....	0.44	.....
H ₂ O.....	29.46	30.79
	100.5	100.00
Deduct O=Cl.....	.53	
	99.99	

The molecular ratios from these figures are Na₂O : CaO : B₂O₃ : H₂O = 16 : 26 : 62 : 163, which conform to no simple formula. If, however, we correct for impurities by throwing out the SiO₂, the K₂O, as KCl, the remaining Cl as NaCl, and the SO₃ as gypsum (CaSO₄, 2H₂O) we can calculate the composition given above, from which we deduce the formula NaCaB₂O₆, 6H₂O, which lies between the two formulas given by Rammelsberg.¹

LUDWIGITE, FROM MORAWITZA, BANAT, HUNGARY.

The material consisted of fine, radiating, silky fibers, almost perfectly black, but showing a tinge of violet when freshly broken, very tough when hammered, but easily cut, associated with quite pure magnetite.

Analysis gave—

B ₂ O ₃	12.04
Fe ₂ O ₃	37.93
FeO.....	15.78
MgO.....	30.57
MnO.....	0.16
H ₂ O.....	3.62
	100.10

The ratios are B₂O₃ : Fe₂O₃ : FeO : MgO : H₂O = 17 : 24 : 24 : 76 : 20. Taking all the protoxides, together with the water, as basic, we have B₂O₃ : Fe₂O₃ : RO = 3 : 4 : 20. G. Tschermak² obtained for boric acid, by Marignac's and by Stromeyer's methods, 16.09 per cent. and 15.06 per cent. respectively, but gives no water; and from his results deduces the formula 3MgO, B₂O₃ + FeO, Fe₂O₃. If he sought for water by ignition, the oxidation of ferrous iron might easily have led to error.

DATOLITE.

The material investigated was the well-known mineral from Bergen Hill, New Jersey, and consisted of crystals about 5^{mm} in diameter, trans-

¹ Pogg. Ann., vol. 97, p. 301.

² Tsch. Min. Mitth., 1874, p. 59.

lucent, white, or of a pale greenish color. I have been unable to find any published analyses of the mineral from this locality, although it has been known for so long a time.

By analysis I obtained—

SiO ₂	35.74
FeO.....	.31
CaO.....	35.14
B ₂ O ₃	22.60
H ₂ O.....	6.14
	99.93

The small amount of iron is undoubtedly present as an impurity leaving this out, the molecular ratios are SiO₂ : CaO : B₂O₃ : H₂O = 60 : 63 : 32 : 34, giving the formula



DANBURITE, FROM RUSSELL, ST. LAWRENCE COUNTY, NEW YORK.

This mineral has been fully described by Profs. George J. rush and Edward S. Dana,² although from the description given by them of the color of their specimen I imagine they had material differing somewhat from mine. The mineral analyzed by me was reddish yellow to pink in color, brilliant in luster, and associated with quartz, pyroxene, and calcite.

In the analysis referred to³ the boric acid was determined by Stro. myer's method. The figures obtained by my analysis are given in the first column; the second is the analysis made by Mr. W. J. Comstock for Professor Brush.

	1.	2.
SiO ₂	49.70	48.23
B ₂ O ₃	25.80	26.93
CaO	23.26	23.24
Fe ₂ O ₃ +Al ₂ O ₃	1.02	.47
Ignition.....	.20	.63
	99.98	99.50

The comparison of the two analyses shows the material difference to be in the amount of impurities.

AXINITE.

Two specimens of this mineral from different localities were analyzed. The first, from Cornwall, England, was of selected crystals of a dark, clove-brown color, translucent, and implanted on quartz. The second

² Am. Jour. Sci., pt. 3, vol. 20, 1880, pp. 111-118.

³ Loc. cit.

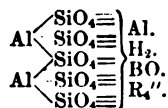
was the axinite from Bourg d'Oisans, Dauphiny, France. This specimen was of a beautiful pearl-gray color, and in some of the smaller crystals almost colorless and quite transparent. The third analysis in the series is one of the Dauphiny axinite, by Rammelsberg, and is copied from his description of the mineral¹ for comparison.

	1 Cornwall.	2 Bourg d'Oisans.	3 Bourg d'Oisans. Rammelsberg.
SiO ₂	42.10	41.53	43.46
Al ₂ O ₃	17.40	17.90	16.33
Fe ₂ O ₃	3.06	3.90	2.80
FeO.....	5.84	4.02	6.78
CaO.....	20.53	21.66	20.19
MnO.....	4.63	3.79	2.62
MgO.....	0.66	0.74	1.73
K ₂ O.....	.....	.....	.11
B ₂ O ₃	4.64	4.62	5.61
H ₂ O.....	1.80	2.16	1.45
	100.66	100.32	101.08

The ratios from the results of analysis No. 2 are: SiO₂ : Al₂O₃ + Fe₂O₃ : (FeO + MnO) + (CaO + MgO) : B₂O₃ : H₂O = 69 : 20 : 51 : 6 : 12, or 10 : 3 : 8 : 1 : 2—giving

B₂O₃ . 3 . R₂'''O₃ . 8R''O . 2H₂O . 10SiO₂, or BR₃'''R₄''H₂ (SiO₄)₅O.

This expression will allow of the graphic formula:



In these analyses the value of R₄ is approximately three atoms of calcium and one atom of iron and manganese taken together. It is therefore probable that axinite is an isomorphous mixture of two species, having R = Ca₃Fe and Ca₃Mn respectively. If we reckon all the R as calcium, we shall have the following theoretical composition:

Al ₂ O ₃	20.9
SiO ₂	41.1
H ₂ O.....	2.5
CaO.....	30.7
B ₂ O ₃	4.8
	100.0

¹ Zeit. d. geol. Gesellsch. XXI, 689.

These results, while differing from those deduced by Rammelsberg from his formula, agree very well with all the results of analysis No. 2. Although the Stromeyer and the Marignac methods of estimating boric acid have been shown to be unreliable, and the determination of any constituent of a mineral by difference is unsatisfactory, nevertheless, by comparing the results of the various analyses, it will be seen that the correctly determined percentages of boric acid do not differ greatly from the older values.

My sincere thanks are due to Mr. H. S. Washington for kindly furnishing the description of the unusual variety of colemanite.

METEORITES FROM JOHNSON COUNTY, ARKANSAS, AND ALLEN COUNTY, KENTUCKY.

BY J. EDWARD WHITFIELD.

1. METEORITE FROM JOHNSON COUNTY, ARK.

A fragment of this meteorite was received by Prof. F. W. Clarke from the former owner, Mr. J. O. Betten, of Eureka Springs, Ark. This fragment weighed a little more than thirty-five grammes; the exposed surfaces were oxidized, the oxide of iron extending into the numerous cracks; in some cases almost through the specimen. The trace of chlorine found by analysis will account in some degree for this oxidation.

The following analysis gives the composition of the iron. The loss is due to the partial oxidation of the iron:

Fe.....	91.87
Ni.....	6.60
Co.....	trace
S.....	0.05
Combined C.....	0.15
P.....	0.41
Mn.....	trace
Cl.....	trace
Insoluble in HCl.....	0.34
	99.42
Specific gravity	7.837

This meteorite has since passed into the hands of Mr. G. F. Kunz, who has fully described it¹, and from his description I copy the main points of interest.

This meteorite is of unusual interest on account of the observance of its fall, which occurred about three o'clock on the afternoon of March 27, 1886. It struck the ground about 75 yards from the house of Mr. Christopher C. Shandy, six miles east of Cabin Creek, Johnson County, Ark. It measures 44^{cm} by 39^{cm}, and weighs 48,732 kilos (107½ pounds). A high ridge 12.5^{cm} high at the highest point runs through the center; one-half the mass is not over 7.5^{cm} thick, part of it is only 5^{cm}, and around the edge it is only 2.5^{cm} or less.

Mr. Kunz gives two figures, which show how very dissimilar the two sides are; the upper side is ridged and deeply dented, while the lower

¹*Am. Jour. Science* for June, 1887.

side is flat, and covered with shallow but very large pittings. The upper side is remarkable for striæ showing the flow and burning, and all running from the center toward the edge, identical with those in the Rowton, Nedagolia, and Mazapil irons, but on a larger scale.

On the upper side ten nodules of troilite are exposed, measuring from 33^{mm} in diameter to 55^{mm} long and 25^{mm} wide; on the lower side there are twelve nodules, the largest measuring 19^{mm} by 39^{mm}. On the upper side these nodules are coated in spots with a black crust similar to that found on the mass, but on the lower side the crust extends completely around the side of the nodules, showing the fusion very plainly. The troilite is very bright, and in some cases where the nodules were broken they were found to be iridescent. This is one of the octahedral iron showing the Widmanstätten figures beautifully on etching, and is one of the Caillite group of Stanislas Mennier and of the Mittlere Lamellen of Brezina.

2. A METEORITE FROM ALLEN COUNTY, KY.

This meteorite was found about the middle of June, 1867, by Mr. James H. More, while hoeing tobacco, near Scottsville, Allen County, Ky. In shape it resembles a wedge, the thickness at base being 14^{cm}, width 18^{cm}, and length 16^{cm}; the mass, as found, weighing a little more than 10 kilos, and having the characteristic pitted surface. A section shows nodules of troilite varying in diameter from barely visible points to about 12^{mm}. The markings on an etched surface are exceedingly fine, and require the aid of a lens to distinguish them. There appear to be two sets of figures, one of long, very fine lines, representing octahedral cleavage, the other series being smaller, more crowded, and barely perceptible. An analysis gave the following composition:

Fe	94.32
Ni.....	5.01
Co.....	trace
S.....	0.34
P.....	0.16
Total C.....	0.12
	99.95
Specific gravity.....	7.848

This iron, as regards markings and general appearance of section, resembles the Scriba and Salt River meteorites more nearly than any others represented in the National Museum collection; but as no complete analyses of these two irons are at hand, the chemical comparison can not well be made. The percentage of iron appears rather high, but duplicate determinations gave corresponding figures.

The material for analysis was received by Prof. F. W. Clarke from Messrs. Ward and Howell, of Rochester, N. Y., the present owners of the meteorite, to whom we are indebted for the privilege of description.

SCORODITE FROM THE YELLOWSTONE PARK.

BY J. EDWARD WHITFIELD.

Among a number of deposits and incrustations, submitted for analysis by Mr. Arnold Hague, of the U. S. Geological Survey, was a specimen from the Joseph's Coat spring, on Broad creek, east of the Grand Cañon. This specimen had a coating of a pale greenish color, the mass consisting of alternate layers of light red or brown and white. At first it was supposed that the green color was due to the organic coloring matter so prevalent in the basins of springs in the Park, but on examination it proved to be a compound containing arsenic and iron. Following are the figures obtained by analysis, on material separated as well as possible from the silica and earthy matter that always accompanies the deposits from the springs:

SiO ₂	4.35
Fe ₂ O ₃	33.29
As ₂ O ₅	46.48
H ₂ O	15.50
SO ₂	.84
	100.46

The analysis shows the presence of some silica and sulphuric acid, but mainly agreeing with the composition of scorodite. Recalculating, leaving out impurities, we obtain the following figures, which agree closely with the theoretical composition of the mineral:

	Calculated.	
Fe ₂ O ₃	34.94	34.7
As ₂ O ₅	48.79	49.8
H ₂ O	16.27	15.5
	100.00	100.0

There are other localities in the Park where scorodite is being deposited. At the Constant Geyser, in Norris basin, the water is thrown out two or three times a minute to a height of from ten to twenty feet. Around the vents the greenish tints are perceptible in the incrustations, but only on the surface, for on breaking the sinter the cross-section shows the thin layers of alternate scorodite and silica; but here the scorodite has been altered to limonite, and the layers are of a brownish color—the nearer the base of the deposit the stronger—the dark color owing to the discoloration of the silica by the oxide of iron.

It is very difficult to scale off the green-colored matter from the surface of this deposit in quantity sufficient for analysis without admixed silica and iron oxide from the layer beneath it. After separating it as well as possible the following figures were obtained by analysis:

SiO ₂	49.83
Al ₂ O ₃	4.74
Fe ₂ O ₃	18.00
As ₂ O ₃	17.37
H ₂ O	10.62
	100.56

Scorodite, as found in the Park deposits, is a very unstable mineral, and only under favorable conditions is it kept from slowly oxidizing, leaving the limonite-carrying varying amounts of As₂O₃.

For a description of the locality and manner of occurrence of scorodite in the Park reference must be made to the paper by Mr. Arnold Hague,¹ in which the whole subject is fully discussed.

¹ Am. Jour. Sci., vol. 34, Sept., 1887.

THE FLOW OF SOLIDS, OR THE BEHAVIOR OF SOLIDS UNDER HIGH PRESSURE.

BY WILLIAM HALLOCK.

THE QUESTION.

Among the many physical questions that are of vital interest to the student of structural geology the one which may well contend for a position in the front rank is, What is the effect of pressure, with or without a rise of temperature, upon the rocks and rock-making magmas which form the outer shells of our earth? As a very important subdivision of this general question we have this: What is the effect of pressures upon so-called solids *without* any rise in temperature above a point far removed from their ordinary melting point? In other words, can we liquefy solids by pressure alone? As corollaries we have any peculiarities at the instant of liquefaction and possible chemical reaction during this state of enforced liquidity.

These questions have long formed the subject of theoretical discussion, but in spite of the fundamental importance of their satisfactory and final settlement, they have seldom been investigated experimentally, doubtless owing to the difficulty of obtaining, measuring, and managing sufficiently high pressures.

Walther Spring may perhaps be rightfully called the pioneer in this work, having within the last few years published the results of much experimental work upon this question. His memoirs¹ would seem to prove without doubt and finally that pressures under 7,000 atmospheres will liquefy the large majority² of solids, and it is only a question of a little higher pressure to accomplish the result even with the most refractory. Further than this, Mr. Spring has investigated the second corollary, and finds that chemical reaction takes place during this fusion;¹ at least when the volume of the products is less than that of the original substances.

Unfortunately, however, for the conclusive character of Mr. Spring's works, they have been seriously called into question, especially by

¹ Bull. de l'Acad. de Belg., 2d ser., vol. 49, 1880, and 3d ser., vol. 9, 1885; and Bull. de la Soc. Chim. de Paris, vol. 39, 1883, and 46, 1886.

² Bull. de l'Acad. de Belg., 2d ser., vol., 49, 1880.

Ch. Friedel.¹ Eduard Jannetaz² repeated many of Spring's experiments, and his results confirm Friedel's criticisms rather than Spring's conclusions, which he (Jannetaz) contradicts in every essential point.

Such was practically the condition of the question two years ago, when the Director of the U. S. Geological Survey, J. W. Powell, requested me to devote my time and thoughts to what we hoped would be its final settlement.³

It would be unjust to leave unmentioned here the elaborate and exhaustive series of experiments made by Henri Tresca⁴ on "the Flow of Solids," which are fundamental as regards the point investigated, which, however, is but a small part of the general question.

In order that my meaning may be clear, I wish for myself and for this paper, to impress certain meanings upon certain terms or words. Primarily, I wish strongly to distinguish between causing a body to "flow" and rendering it a true liquid. Any substance may "flow" when the force acting to cause the molecules to change their relative positions is greater than the force with which the molecules are held in their original positions; i. e., is greater than the rigidity or viscosity of the substance. This can occur from two causes: an increase of the force tending to disturb the molecules, or a diminution of the resisting power, the rigidity of the material. The first cause may take the form of pressure, strain, or such like force; the second cause is heat, and possibly other agencies. Whether rupture or flow takes place when the deforming overcomes the resisting force depends upon the nature of the substance, its limiting conditions, and *the time allowed for the accomplishment of the motion.*

It is impossible to draw a sharp line between "liquids" and "solids;" for convenience they may well be classed as true liquids, viscous liquids, viscous solids, true solids. In the first class would fall such substances as, in a small fraction of a second, fill their containing vessel to a horizontal surface. As true liquids we should then have such as alcohol, water, glycerine, molasses, etc. Viscous liquids require several seconds to fill their containing vessel to a level surface; thick tar is a good example. When the substance requires hours or even weeks in which to yield to gravity and change its form, I would call it a viscous solid; paraffine, shoemaker's-wax, and even lead and some other metals are such. A true solid retains its original shape indefinitely under ordinary conditions of pressure and temperature, as steel, glass, etc. Of course such a thing as an *absolutely or perfectly* rigid substance is as unknown to us as is an *absolute or perfect* fluid.

¹ Ch. Friedel, Bull. de la Soc. Chim. de Paris, vol. 39, 1883, p. 626.

² Ed. Jannetaz, Bull. de la Soc. Chim. de Paris, vol. 40, 1884; Bull. de la Soc. Minéral. de France, vol. 8, 1885, p. 168.

³ This paper is essentially taken from a report made to Major Powell, dated at Watertown, Mass., September, 1885. (See foot note on page 75.)

⁴ Henri Tresca, Mém. de l'Inst. Savantes Étrangers, vol. 18, 1868. Comptes Rendus, vol. 66, 1868; lxxviii, 1869. See Tresca, in Bibliography, p. 75.

If the above ideas are correct, "true liquefaction" is the diminishing of the rigidity or viscosity of a substance until its molecules change their relative positions as easily as in a true liquid.

I give these definitions merely that I may be understood in the use of these terms, and not because I think them new or especially good. In order that a substance may undergo a change in its chemical or crystalline character, it is undoubtedly necessary that it should be in the condition, at least, of a viscous solid, so that the molecules can slowly rearrange themselves, if there be any force urging them thereto. Our question is, will pressure alone impart to the molecules such a freedom of motion? *A priori* it is inconceivable to me how or why it should. For with the exception of a few isolated substances at particular temperatures—as water between 4° C. and ice at zero—an increase of liquidity or a diminution of rigidity is simultaneous with an increase of volume, that is, with an increase of the intermolecular distances, which is accomplished by "heating" the substance. *In general*, for one and the same substance over considerable ranges of condition, the rigidity diminishes as the intermolecular distances increase. How, then, can pressing the molecules nearer together be expected to give them a property which always accompanies their separation?

THE APPARATUS.

The first requisite for the experiments was pressure, and naturally desiring the best machine, we were able, through the kindness of General Benét, Chief of Ordnance, to have the use in its spare moments of the testing-machine built by A. H. Emery for that department, and situated at Watertown, Mass. This machine undoubtedly enables the operator to obtain, measure, and manage high pressures better than any other.

Personally, I am greatly indebted to Capt. J. Pitman, of the Ordnance Corps, for suggestions as well on the construction of the holders as on the theoretical points; and also to Mr. J. E. Howard, the engineer in charge of the testing-machine, for his knowledge of the capacity of materials, and their best shape and quality to obtain the results desired. The apparatus was constructed by the American Tool and Machine Company of Boston, Mass.

For the preliminary tests it seemed desirable to have a holder which could be opened, so as to show the compressed material in position, and finally the following form was adopted:

Fig. 15 shows a section across the holder on the plane B B of Fig. 14, which in turn is a section on A A of Fig. 15. E E are the two halves in contact at *h h*, inclosing the cylindrical hole F, in which the substance to be pressed is placed. *h h* are strips of tissue paper, used as packing between the two halves. II and I'I', Fig. 14, are the two pins, acting as pistons, fitting into the hole F, to transmit the pressure; *a a* and *a a* are copper "gas-checks," placed in front of these pins, to flare

out and fill tightly the hole, preventing any escape of material. Figures 14 and 15 are one-fifth natural size. Pl. I shows the manner in which the apparatus was held in the testing-machine and the pressure applied. P P P and P' P' P' are the jaws of the hydraulic clamps of the machine (capacity 1,000,000 pounds). H H are merely blocks to enable the clamp to properly hold the holder E E. N is a block to hold the back stationary pin in place. The lettering in Figs. 14 and 15 apply in Pl. I. V V is the hydraulic clamp on the fixed end of the testing-machine where the pressure is weighed. The block B B moves on a spherical surface

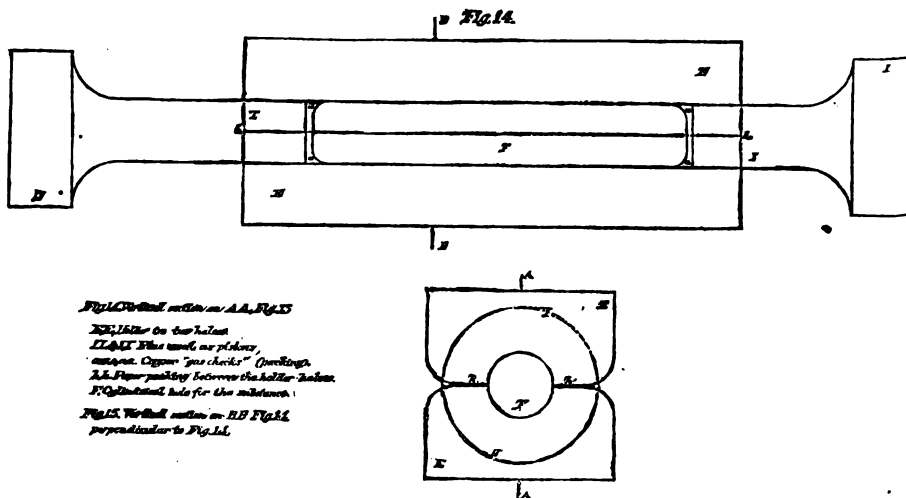


Fig. 14. Side view of the holder assembly.

Fig. 15. Top-down view of the holder assembly.
 Labels: P (jaws), H (blocks), N (block), V (clamp), B (block).

Fig. 15. Top-down view of the holder assembly, perpendicular to Fig. 14.

FIGS. 14, 15.—Diagram of apparatus used in work on high pressures.

(R R R) on the plate T T T, thus permitting the adjustment of the face of O perpendicular to the line of pressure or parallel to the rear surface of the pin I I. To apply the pressure, the movable clamp P P' is forced toward V V by a hydraulic piston, thus forcing the holder E E over the pin resting against O; the pressure on O is measured by the hydraulic balance of the machine. In this manner a total compressive power of one million pounds was available, but as the pins yielded at 110,000 pounds per square inch, the tests were not carried above 6,409 atmospheres, or 96,000 pounds per square inch.

EXPERIMENTS.

With the above apparatus, used as described, the following tests were made:

FIRST TEST.

A paper roll containing 1.557 pounds "c. p. granulated lead" was placed in the hole F, the gas-checks and pins were inserted, the holder halves clamped together, and the pressure was *slowly* applied; the amount of compression was measured in the distance to which E E had been forced over the right-hand pin. Multiplying the simultaneous

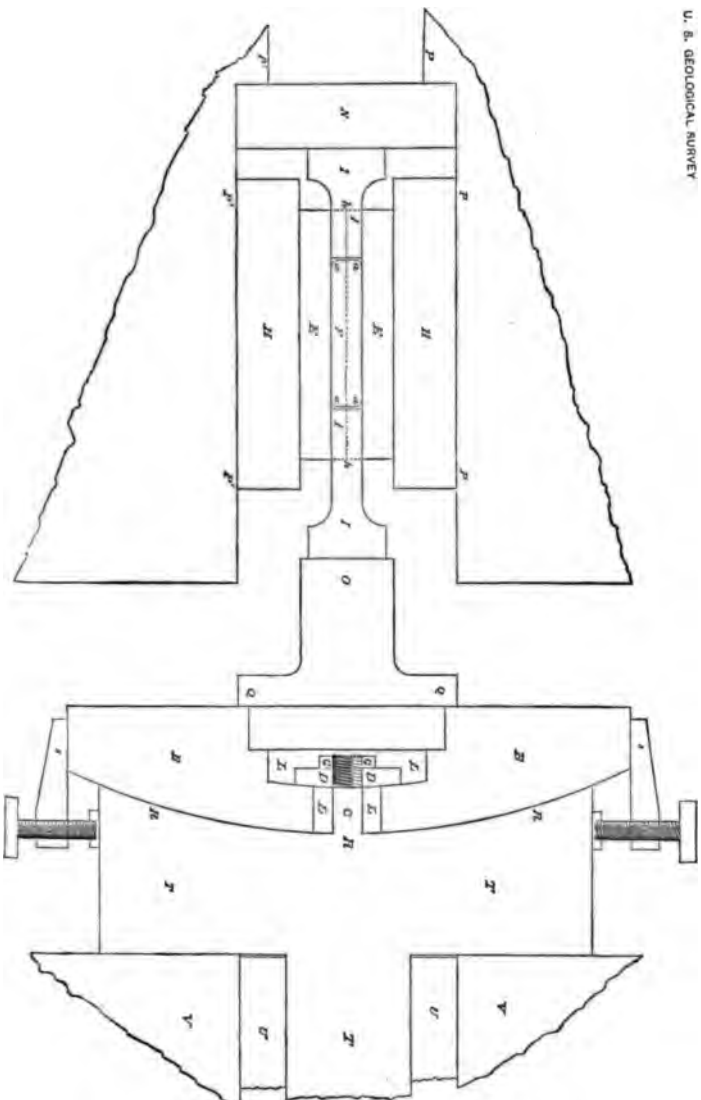


DIAGRAM OF APPARATUS USED IN WORK ON HIGH PRESSURES.

loads and compressions, we obtain the *work* done, and hence the possible heat generated. In this experiment the work done was 2,330 foot-pounds, or 3.0 thermal units, 1 pound 1° F., sufficient to raise 1.557 pounds lead *alone* about 63° F., or 34° C. If the heat generated is dissipated into the holder E E, as is sure to be the case, the rise in temperature would be less than 1° C., or $1^{\circ}.8$ F.

Under a pressure of 6,000 atmospheres the granular lead showed not the least sign of true liquefaction. It was merely pressed together, and could easily be broken up and reduced to the original grains between the thumb and finger. It is true these experiments were not performed *in vacuo*, a condition which Walther Spring considers of importance. But if there is a true liquefaction, why does not the air rise to the top of the cavity and allow fusion, as it does when the granular lead is heated? There is no liquefaction, only a pressing and sticking together.

SECOND TEST.

Next 0.672 pounds¹ of antimony was ground in a mortar until it went through a 48-sieve, and then it was similarly submitted to 6,000 atmospheres pressure, with the same result; the grains were simply stuck together, and were perfectly distinct in their original form. The cylinder formed was hard and tenacious, but gave no signs of liquefaction or recrystallization. The work done in this case might have raised the antimony alone 230° F., or 110° C., or holder and antimony $1^{\circ}.8$ F., or 1° C.

THIRD TEST.

Well-crystallized calcite, 0.271 pounds,² was ground, put through a 48-sieve, and submitted to a pressure of 6,000 atmospheres, producing practically no effect; the resulting mass being easily broken between the thumb and finger.

Finding it useless to have large quantities of the compressed material for elaborate examination, it was decided to expedite matters by putting in several substances at one time, and the following rather crucial test was made:

FOURTH TEST.



FIG. 16.—Diagram showing experiment.

L H, left-hand pin, stationary. R H, right-hand pin, entering the hole F, moving.

¹ 0.672 pounds antimony, solid, filled the hole F, 5 inches long.

² 0.271 pounds of solid calcite fills the holder, 5 inches in length.

The charge was composed as follows:

- A. Small section of antimony from test II.
- B. A stick of bees-wax whittled round, nearly fitting the hole.
- C. A stick of paraffine whittled round, nearly fitting the hole.
- D. Bismuth prepared like the antimony for test II.
- E. Paraffine, same as C.
- F. Lead from test I.

d d were double-pointed tacks stuck into the top of the bees-wax and paraffine, and at *a* and *c* two old *silver* 3-cent pieces were laid on top of the wax and the paraffine in the cylinder.

What are we to expect? The silver pieces and tacks would fall through the liquid wax and paraffine, and B and C, if liquid, would mix. Nay, according to Spring's results, we should expect to find along the lower part of the mold a semi-cylindrical piece of an alloy of lead, antimony, bismuth, possibly silver and iron, and above this the mixture of paraffine and wax. The actual result was that the substances *all came out just as they went into the press*. There was not the slightest trace of a tendency to flow on the part of the metals; the lead and antimony remained as they were, the bismuth acted precisely as did the antimony in test II. There was no sign of fusion of the wax and paraffine, which separated on their surface of contact (between B and C) clear and distinct. *a, c, d*, and *d* did not sink to the bottom—on the contrary, they retained their original positions; and the silver pieces were forced against the top of the cylinder so powerfully, that their impression left in the steel holder was easily seen and *felt*, and the pieces were bent cylindrical, fitting the inside of the holder. Here we find a much greater rigidity of wax and paraffine under pressure than ordinarily supposed possible under any circumstances.

Nowhere was there a sign of true liquefaction. The wax and paraffine had acted only as viscous solids, and flowed only to fill the available opening.

FIFTH TEST.

In a similar way the following substances were subjected to a pressure of 6,000 atmospheres, with the results as stated:

Sodium carbonate, dry.—Stuck together slightly, resembling chalk; easily cut with a knife.

Sodium sulphate.—Probably dissolved in its water of crystallization ($10\text{H}_2\text{O}$); it was forced out between the halves of the holder as a milky liquid which solidified. The little left in the holder resembled paraffine in appearance, but soon weathered to a white powder.

Zinc sulphate ($+7\text{H}_2\text{O}$).—No signs of fusion; merely stuck together; the original pieces of crystals easily visible.

Copper sulphate ($+5\text{H}_2\text{O}$).—Same as zinc sulphate.

SIXTH TEST.

Potassium chloride.—Formed a hard lump, whose fracture resembled that of loaf sugar or that of marble, with the original crystals visible; no trace of fusion.

Sodium chloride.—Similar to potassium chloride, only a little more compact.

Ammonium chloride.—Still more compact, resembles vegetable ivory; possibly the beginning of fusion. Observe the order of increasing effect:



Sulphur roll.—Ground and put through a 48-sieve; formed a hard, solid, brittle mass, but the original grains were easily distinguishable, there being no trace of a true liquefaction.

SEVENTH TEST.

Powdered glass.—No effect; scarcely coherent.

Powdered rosin.—Very good fusion.

Powdered borax.—A compact, chalk-like mass, *slightly* translucent; no crystallization.

Powdered zinc and sulphur.—No trace of fusion or chemical union apparent. Carbon disulphide dissolved out the sulphur so completely, that the remaining zinc gave a mere trace of sulphureted hydrogen on treating with hydrochloric acid. The zinc was slightly coherent, but there was no fusion and no zinc sulphide formed.

After obtaining the above results it seemed useless to continue this line of experiments, and preparations were made to use more rigid steel, by which it was hoped that pressures of at least 10,000 atmospheres might be obtained; also for making the compressions *in vacuo*. Unfortunately thus far nothing but preparations have been made, since the testing-machine is kept fully occupied with the special work of the department to which it belongs. It is hoped, however, that this investigation will soon be taken up again and carried to a close; till then our conclusions are only temporary.

The above substances were also compressed by W. Spring¹ in *vacuo* with the following results:

Lead.—Perfect fusion at a pressure of 2,000 atmospheres. At a pressure of 5,000 atmospheres it ran out of all the cracks (*fentes*) of the apparatus.

Bismuth.—At a pressure of 6,000 atmospheres, perfect fusion.

Tin.—At a pressure of 3,000 atmospheres, fusion.

Zinc.—At a pressure of 5,000 atmospheres, perfect fusion.

Antimony.—At a pressure of 5,000 atmospheres, beginning of fusion.

Sulphur, prismatic.—At a pressure of 5,000 atmospheres, fusion to the octahedral form.

Sulphur, plastic.—At a pressure of 6,000 atmospheres, fusion to the octahedral form.

Sulphur, octahedral.—At a pressure of 3,000 atmospheres, fusion to the octahedral form.

Potassium chloride.—At a pressure of 5,000 atmospheres, perfect fusion.

Sodium chloride.—At a pressure of 5,000 atmospheres, perfect fusion.

Ammonium chloride.—At a pressure of 4,000 atmospheres, perfect fusion.

Sodium sulphate (10H₂O).—At a pressure of 3,000 atmospheres, perfect fusion.

Zinc sulphate (7H₂O).—At a pressure of 5,000 atmospheres, perfect fusion.

Copper sulphate (5H₂O).—At a pressure of 6,000 atmospheres, completely crystallized.

Sodium carbonate, dry.—At a pressure of 5,500 atmospheres, stuck together (*aggloméré*).

Iceland spar.—At a pressure of 6,000 atmospheres, imperfect fusion.

Borax (crystallized).—At a pressure of 7,000 atmospheres, imperfect fusion.

Glass (powdered).—At a pressure of 6,000 atmospheres, no effect.

And so on to the end.

¹ Bull. de l'Acad. R. de Belg., II, xlix, 1880. (See foot-note on page 75.)

Excepting the last four substances mentioned, our results are directly opposed to those of Spring, but support the criticisms of Friedel and Jannetaz.

CONCLUSIONS.

Conclusions at this stage of the investigation are necessarily premature and tentative; still it may not be out of place to summarize the results of these and other experiments.

It seems established that pressure alone can not truly liquefy a solid, i. e., diminish its rigidity. Consequently, we can scarcely expect chemical and crystalline changes by pressure alone. Solids can be made to flow and act in that respect, as liquids, by pressure, which overcomes the rigidity without diminishing it. In this case the time allowed for the motion is of vital importance.

Whether further investigation will alter these conclusions or not is a question of time; at present, I believe them the only true ones to be drawn from the available facts.

REFERENCES TO THE LITERATURE.

- BATTELI and PALAZZO. On the change of volume of some substances on melting. *R. Acc. dei Lincei*. 1. 1885. pp. 1-20.
- A. BATTELI. Influence of pressure on the melting point of some substances. *Atti del R. Ist. veneto di Sc. ed Arti*. (6). 3. 1885.
- Also, *Il Nuovo Cimento* (3). 19. 1886. pp. 232-243.
- *Atti del R. Ist. veneto di Sci. ed Art.* (3). 1886. p. 35.
- JAMES THOMSON BOTTOMLEY. Melting and regelation of ice. *Nature*, vol. 5, p. 185 (January 4). 1872.
- R. BUNSEN. Rise of the melting point with pressure. *Pogg. Ann.* 81. 1850.
- L. CAILLETET. Effect of pressure on chemical action. *Naturforscher*. 5. p. 4.
- MICHAEL FARADAY. Regelation. *Proc. Roy. Soc.* 10. 1860. p. 430, and *Pogg. Ann.*, 111, 1860. p. 647.
- FORBES. Regelation of ice. *Phil. Mag.* (4). 16. 1858. p. 544.
- ED. FREMY. Formation of coal by pressure. *Comptes Rendus*, 88. 1879. p. 1048. May 26.
- CH. FRIEDEL. Criticism of the work of W. SPRING. *Bulletin de la Société Chimique de Paris*. 39. 1884. p. 626. Reviewed by W. S. B., *Amer. Chem. Jour.* 6. 1884. p. 129.
- G. P. GRIMALDI. On the variation by pressure of the temperature of maximum density of water. *Gazz. Chim. Ital.* 15. 1885. p. 297.
- R. VON HELMHOLTZ. The change of melting point calculated from the vapor tension of ice. *Wiedemann Ann.* 30. 1877. p. 401-432.
- HOPKINS. Rise of melting and boiling point with pressure. *Dingler's Polyt. Journ.*, 134. 1854.
- ED. JANNETAZ with NEEL & CLERMONT. Note on the crystallization of substances under high pressure. *Bulletin de la Soc. Chim. de Paris*. 40. 1884. p. 51.
- Effects of compression on quartz. *Bulletin de la Soc. Minéral. de France*. 8. 1885. p. 168.
- E. MALLARD and H. LE CHATELIER. On the variation with pressure of the temperature at which the transformation of iodide of silver takes place. *Bulletin de la Soc. Minéral. de France*. 7. 1884. p. 478-484.
- W. PEDDIE. Note on the variation by pressure of the melting point of paraffine, etc. *Proc. Edin. Roy. Soc.*, 1884-85. No. 120. pp. 155-157.

- F. PFAFF. Effect of pressure on chemical action. Neues Jahrbuch für Mineralogie, etc. 1871. pp. 834-839.
- Plasticity of ice. Pogg. Ann. 155. 1875. p. 169. Also, Sitzungs-Ber. der phys.-med. Societät zu Erlangen. 1875. Heft 7. p. 72.
- L. PFAUNDLER. Regelation of ice. Der Naturforscher. 2. 1869. p. 371.
- F. E. REUSCH. Deformation of ice. Pogg. Ann. 125. 1865. p. 304.
- CARL SCHULTZ. On the freezing point of water out of gas solutions and on the regelation of ice. Pogg. Ann. 137. 1869. p. 252.
- WALTHER SPRING. Researches on the property which substances possess of fusion (*de se souder*) under pressure. Bulletin de l'Acad. Roy. de Belg. 2d series. 49. 1880. p. 323-379.
- On chemical union by pressure. Bulletin de la Soc. Chim. de Paris. 39. 1883. p. 641.
- Reaction between sulphate of barium and carbonate of sodium under the influence of pressure. Bulletin de l'Acad. Roy. de Belg. 3d series. 9. 1885. p. 204-208. Continued in Bulletin de la Soc. Chim. de Paris. 46. 1886. p. 299.
- SAINT VENANT. Motion of liquid, or ductile solid particles flowing through an orifice. Part I. Comptes Rendus. 66. 1868. p. 1311-1324. Part II. Comptes Rendus. 68. 1869. p. 290-301.
- JAMES THOMSON. Theoretical considerations on the effect of pressure in lowering the melting point of ice (freezing point of water). Trans. Roy. Soc. Edin. 16. 1849. p. 575-581.
- WILLIAM THOMSON. Melting point of ice lowered by pressure. Phil. Mag. [3]. 37. 1850. p. 123.
- HENRI TRESCA. On the flow of solids. Mémoires de l'Institut, Savants Étrangers Sci., Math. et Phys. 18. 1868. p. 733-799.
- Also, Comptes Rendus. 66. 1868. p. 263-270.
- On the application of the formulæ for the motion of permanent liquids to the flow of solids. Comptes Rendus. 66. 1868. p. 1027-1032, 1244-1246, and 1305-1311.
- On punching and the mechanical theory of the deformation of metals. Comptes Rendus. 68. 1869. p. 1197-1201.
- On the flow of solids. Mémoires de l'Institut, Savants Étrangers Sci. Math. et Phys. 20. 1872. p. 75-137.
- Application of the flow of solids to rolling and punching. Mémoires de l'Institut Savants Étrangers Sci. Math. et Phys. 20. 1872. p. 137-185.
- Continuation of the article on the flow of solids. Mémoires de l'Institut Savants Étrangers Sci. Math. et Phys. 20. 1872. p. 281-287.
- On the flow of solids and the punching of metals. Mémoires de l'Institut, Savants Étrangers Sci. Math. et Phys. 20. 1872. p. 617-838.

An abstract of the foregoing article appeared in the American Journal of Science, vol. 34, 3d series, 1887, p. 277. In a note published in the same journal (vol. 35, 1888, p. 78), Mr. Spring violently attacks my interpretation of our results, especially my use of the word "fusion," which I have employed in its secondary sense, as meaning *a uniting as if by melting with heat*; the case of actual fusion by heat being specifically excluded. It seemed to me best to leave the word in the above article and make this explanation of its use. See, also, W. Spring, Bull. Acad. roy. Belg., vol. 16, 1888, p. 43; also Am. Jour. Sci., vol. 36, 1888, p. 286. And, W. Hallock, Am. Jour. Sci., vol. 36, 1888, p. 59; also *ibid.*, vol. 37, 1889, p. 402; also Zeitschr. für Phys. Chem., vol. 2, 1888, p. 378.

MISCELLANEOUS ANALYSES.

**FELDSPAR. FROM A FELDSPATHIC MICA SCHIST, CENTRAL SHAFT
OF THE HOOSAC TUNNEL, MASS.**

[Collected by J. E. Wolff. Analyses by R. B. Riggs.]

SiO ₂	69.69
Al ₂ O ₃	18.60
Fe ₂ O ₃	trace
CaO	trace
MgO	.20
Na ₂ O	10.28
K ₂ O	.40
Ignition	.42
	99.59

**TWO FELDSPARS. FROM THE PORPHYRITIC MICA SCHIST OF GREY-
LOCK MOUNTAIN, MASS.**

[Collected by J. E. Wolff. Analyses by R. B. Riggs.]

	I.	II.
SiO ₂	68.08	67.83
Al ₂ O ₃ , Fe ₂ O ₃	20.11	19.92
MnO	trace	trace
CaO	trace	trace
MgO	trace	trace
Na ₂ O	11.60	11.65
K ₂ O	.36	.25
Ignition	.31	.12
	99.86	99.77

In neither case does the Fe₂O₃ exceed .5 per cent.

THREE FELDSPARS FROM DELAWARE.

[Separated by J. S. Diller from rocks collected by Prof. F. D. Chester. Analyses by R. B. Riggs.]

A. Specific gravity, 2.592-2.877. From a typical gabbro. Brandywine Creek.

B. Specific gravity, 2.592-2.749. From Iron Hill hyperite, changing to diorite. Near Whitaker's ore-pit.

C. Specific gravity, 2.592–2.780. From a typical hypersthene gabbro Fifth and Van Buren streets, Wilmington.

	A.	B.	C.
SiO ₂	70.37	44.09	51.44
Al ₂ O ₃	18.36	35.41	30.05
Fe ₂ O ₃	.58	.51	.96
MnO	trace	trace	.....
CaO	5.08	18.47	13.19
MgO	.04	none	trace
Na ₂ O	4.32	.99	4.07
K ₂ O	.63	.19	.21
Ignition	.45	.35	.35
	99.83	100.01	100.27

B is evidently anorthite.

TRIASSIC SANDSTONE FROM MARYLAND.

A hard, compact building stone, from the Jaittelle quarry, near Hancock. Color, rich reddish brown. Analysis by F. W. Clarke.

A. Analysis by fusion with alkaline carbonates.

B. Analysis by solution in strong HCl.

	A.		B.
Ignition	2.79	Insoluble	88.68
SiO ₂	76.43	Fe ₂ O ₃	7.13
Al ₂ O ₃ , Fe ₂ O ₃	17.78	CaCO ₃	1.32
CaO	.84	MgO	.66
MgO	.92	H ₂ O	2.20
MnO	trace		
Alkalies	undet.		99.99
	98.76	Residue nearly white.	

LIMESTONE FROM THE AUGLAIZE RIVER, NEAR DEFIANCE, OHIO.

Highly bituminous. Nearly black, resembling a slate. Contains visible pyrite. Partial analysis J. Edward Whitfield.]

Ignition	24.03
SiO ₂	39.95
Fe ₂ O ₃ , Al ₂ O ₃	20.22
MnO	trace
CaO	10.06
MgO	2.92
Alkalies	undet.
S (pyritic)	undet.
	97.18
CO ₂ in carbonates	12.49
Organic carbon	5.29

MISCELLANEOUS ANALYSES

TWELVE ROCKS FROM MENOMONEE RIVER, MICHIGAN AND WISCONSIN

[Collected by R. D. Irving. Analyses by R. B. Riggs.]

- A. Massive diabase. Lower Quinnessec Falls, Wisconsin side.
- B. Green chloritic schist. Shore just below Lower Quinnessec Falls, Wisconsin side.
- C. Light gray gabbro, from near B.
- D. Schistose gabbro, adjoining C.
- E. Silvery schist, adjoining D.
- F. Light-colored gabbro. Barrier Rock, at Sturgeon Falls, Michigan side.
- G. Adjoining and similar to F; altered and somewhat schistose.
- H. Silvery schist, adjoining G.
- I. Uralitic gabbro. Barrier Rock, Big Quinnessec Falls.
- J. Dark-gray granite. Small cove just below the "Horse-Race," Quinnessec Falls, Wisconsin side.
- K. "Augengneiss," with red feldspar. Lower end of "Horse-Race," Big Quinnessec Falls, Michigan side.
- L. Porphyroid. Just below Big Quinnessec Falls, Wisconsin side.

	A.	B.	C.	D.	E.
SiO ₂	43.80	44.49	47.96	49.19	46.21
Al ₂ O ₃	16.08	16.37	16.85	18.71	18.38
Fe ₂ O ₃	9.47	5.07	4.33	5.03	3.30
FeO.....	10.50	5.50	4.17	4.04	3.90
CaO.....	7.81	7.94	13.25	5.92	6.28
MgO.....	6.54	7.50	9.15	7.98	7.03
Na ₂ O.....	1.96	2.59	1.25	1.44	2.14
K ₂ O.....	.34	.56	.30	.77	.35
H ₂ O.....	3.99	4.99	2.89	5.05	3.82
CO ₂	0.8	5.38	.08	1.82	8.32
	100.57	100.39	100.23	99.95	99.73
	G.	H.	I.	J.	K.
SiO ₂	38.05	45.70	48.35	54.83	67.77
Al ₂ O ₃	24.73	16.53	15.40	25.49	16.61
Fe ₂ O ₃	5.65	4.63	4.04	1.61	2.06
FeO.....	6.08	3.89	4.63	1.65	1.96
CaO.....	1.25	4.28	10.38	6.08	1.87
MgO.....	11.58	9.57	11.61	1.96	1.26
Na ₂ O.....	2.54	.55	1.87	5.69	4.35
K ₂ O.....	1.94	3.82	.35	1.87	2.35
H ₂ O.....	7.53	4.70	3.60	1.18	1.69
CO ₂	.93	5.95	.08	.18	.19
	100.28	99.62	100.31	100.54	100.11

ROCKS FROM PIGEON POINT, MINN.

[Collected by R. D. Irving.]

- A. Average granite rock. Analyst, W. F. Hillebrand.
- B. Red granite, part of A. Analyst, J. Edward Whitfield.
- C. Soda orthoclase from A. Analyst, J. Edward Whitfield.

D. Altered quartzite in contact with B. Analyst, J. Edward Whitfield.

E. Typical olivine gabbro. Analyst, W. F. Hillebrand.

F. Augite from gabbro; partial analysis. Analyst, R. B. Riggs.

G. Rock occurring between A and E. Analyst, W. F. Hillebrand.

H. Quartz porphyry. Analyst, W. F. Hillebrand.

I. Mottlings (greenish) from H. Analyst, W. F. Hillebrand.

J. Groundmass of H. Analyst, W. F. Hillebrand.

K, L, M, N, O, P, Q, R. Altered quartzites. Analyst, R. B. Riggs.

	A.	B.	C.	D.	E.
SiO ₂	72.16	68.36	65.00	63.82	49.88
TiO ₂	.39	1.57	.....	2.66	1.19
Al ₂ O ₃	12.98	13.76	18.22	14.65	18.55
Fe ₂ O ₃	.67	2.65	2.64	3.16	2.06
FeO.....	2.99	2.75	.....	5.12	8.37
MnO.....	.09	trace	.....	none	.09
CaO.....	.65	.70	1.06	.70	9.72
SrO.....	?	undet.	.....	undet.	trace
BaO.....	.15	undet.	.....	undet.	.02
MgO.....	.57	.68	.06	2.08	5.77
K ₂ O.....	4.94	4.48	4.18	2.81	.68
Na ₂ O.....	3.42	3.56	8.40	1.95	2.59
Li ₂ O.....	none	none	.....	none	none
H ₂ O.....	1.20	.98	.46	2.62	1.04
P ₂ O ₅	.20	.33	.....	.19	.16
Cl.....	trace	.....	.....	.....	trace
SO ₃.....	.....	.66	.....	.33	.....
	100.41	100.48	100.02	100.09	100.12
	F.	G.	H.	I.	J.
SiO ₂	48.34	57.98	74.00	77.70	76.57
TiO ₂	1.98	1.75	.34	.30	.42
Al ₂ O ₃	2.90	13.58	12.04	7.67	9.21
Fe ₂ O ₃	4.68	3.11	.78	3.55	1.67
FeO.....	14.15	8.68	2.61	3.29	3.94
MnO.....	.....	.13	.05	.04	.05
CaO.....	15.10	2.01	.85	.26	.73
SrO.....	.....	trace	trace	?	trace?
BaO.....	.....	.04	.12	none	none
MgO.....	11.34	2.87	.42	1.83	1.51
K ₂ O.....	.....	3.44	4.33	1.04	1.02
Na ₂ O.....	.....	3.56	3.47	1.96	3.07
Li ₂ O.....	.....	trace	trace?	trace	trace
H ₂ O.....	.....	2.47	.86	2.36*	1.89
P ₂ O ₅.....	.....	.29	.06	none	trace
Cl.....	.....	trace	trace	.....	.....
	.....	99.91	99.93	100.00	100.03

* By difference.

MISCELLANEOUS ANALYSES.

83

	K.	L.	M.	N.
.....	73.14	71.00	74.92	73.65
.....	.04	.44	.16	trace?
.....	12.60	12.88	10.61	11.08
.....	7.57	6.69	7.45	7.24
.....	1.31	.65	.85	.77
.....	trace	trace	none	trace
.....	.43	.21	.56	.40
.....	undet.	undet.	undet.	undet.
.....	undet.	undet.	undet.	undet.
.....	1.67	1.68	1.48	1.52
.....	1.78	1.43	2.12	1.67
.....	1.00	2.95	1.08	1.65
on	.83	2.03	1.79	1.88
	100.37	99.96	100.32	99.86
	O.	P.	Q.	R.
.....	72.25	83.69	73.64	59.71
.....	trace	trace?	trace	trace
.....	10.73	7.50	11.25	18.32
.....	8.01	1.81	6.24	8.11
.....	38	.38	1.04	.85
.....	trace	trace	none	none
.....	.42	.39	.36	1.05
.....	undet.	undet.	undet.	undet.
.....	undet.	undet.	undet.	undet.
.....	1.85	.35	1.57	3.54
.....	2.03	2.46	3.04	1.93
.....	2.56	2.61	1.42	3.43
ion	2.05	.72	1.98	3.24
	100.28	99.91	100.54	100.18

TWO ROCKS FROM MONTANA.

[Collected by A. C. Peale. Analyses by T. M. Chatard.]

.. From Cottonwood Creek. B. Hills east of Fort Ellis.

	A.	B.
H ₂ O	3.19	5.42
SiO ₂	51.65	46.90
TiO ₂	.55	.41
P ₂ O ₅	.21	.44
SO ₃	.19	.....
Al ₂ O ₃	13.89	10.17
Cr ₂ O ₃	.08	.33
Fe ₂ O ₃	2.70	1.22
FeO	4.80	5.17
MnO	.15	.10
BaO	.19	.....
SrO	undet.	.....
CaO	4.07	6.20
MgO	11.56	20.93
K ₂ O	4.15	2.04
Na ₂ O	2.99	1.16
	100.37	100.54

Comparations from B. Partial analyses.

	Groundmass.	Pyroxene.
Ignition	5.40	.....
SiO ₂	65.58	51.95
Al ₂ O ₃	{ 14.94	4.21
Fe ₂ O ₃		
FeO .....	.....	5.90
CaO	3.60	23.32
MgO	3.45	13.81
		99.19

FIFTEEN ROCKS FROM CALIFORNIA.

ted by J. S. Diller. Analyses A, B, C, by T. M. Chatard; D, by W. F. Hillebrand and T. M. Chatard; E, by R. B. Riggs; and the remainder by W. F. Hillebrand.]

Basalt, from 1 mile southeast of Paine's Creek, on road from Red to Lassen Peak.

Ancient lava. Old crater at head of Mill creek.

Lava, from Buntingville.

Basalt. Top of Inskip Crater, 25 miles east of Red Bluff.

Lava. Above falls on south fork of Bear Creek, Shasta County.

Basalt. Cinder Cone, 10 miles northeast of Lassen Peak.

Basalt. One mile east of summit of Cascade Range, on road from Klamath to Crater Lake.

Andesite lava. One mile west of Summit, on Bidwell's Road, Siskiyou County.

Lava. West end of Butte Mountain, Plumas County.

Andesite. Tuscan Buttes, 7 miles east of Red Bluff.

Ancient lava. Northeast of Willow Lake, near Geyser, Plumas County.

Lava. Two miles northwest of Deer Creek meadows.

Lava. Slate Creek, west of Deer Creek meadows.

Lava. Slate Creek, northwest of Deer Creek meadows Lassen

Lava. Summit of Mount Stover, Plumas County.

	A.	B.	C.	D.	E.
.....	47.93	57.11	67.89	50.89	68.10
.....	.73	.95	.21	.79	.15
.....	18.51	17.78	17.29	16.76	15.50
.....	2.07	3.54	2.39	3.86	3.20
.....	7.25	2.74	.21	4.69	none
.....	.20	.33	.12	.13	trace
.....	11.14	7.21	3.01	11.72	3.02
.....	.....	trace ?	.04	.....	trace
.....	.....	.03	.03	trace	.06
.....	9.03	3.41	.66	8.49	.10
.....	.24	1.86	1.69	.32	3.13
.....	2.28	3.81	5.11	2.61	4.20
.....	.....	.....	.....	.....	none
.....	.76	.93	1.34	.41	2.72
.....	.11	.26	.12	.09	.03
	100.25	100.01	100.11	100.76	100.21

MISCELLANEOUS ANALYSES.

85

	F.	G.	H.	I.	J.
.....	57.25	57.47	55.20	55.53	60.93
.....	.60	.75	.92	.56	.61
.....	16.45	18.86	18.68	17.63	18.56
.....	1.67	2.21	3.14	2.81	2.68
.....	4.72	4.08	4.42	3.59	2.19
.....	.10	.10	.14	.08	.10
.....	7.65	7.42	8.02	8.74	6.63
.....	trace	.11	.02	.06	.12
.....	.03	.03	.03	.02	.02
.....	6.74	4.27	4.59	5.85	2.37
.....	1.57	.73	1.01	.92	1.33
.....	3.00	3.85	3.66	3.09	3.79
.....	none	none	none	none	none
.....	.40	.22	.51	1.24	.90
.....	.20	.24	.24	.21	.18
	100.38	100.34	100.58	100.33	100.41
	K.	L.	M.	N.	O.
.....	74.24	74.65	73.62	73.64	72.40
.....	.20	.21	.21	.11	.18
.....	14.50	14.11	14.24	13.44	14.81
.....	1.27	1.08	.93	.60	.81
.....	.67	.29	.67	.74	.88
.....	.06	.11	.08	.06	.07
.....	.11	.80	1.07	1.26	1.94
.....	trace	trace	trace	.02	.04
.....	.18	.08	.10	.11	.10
.....	.25	.20	.33	.26	.47
.....	3.66	4.59	4.28	4.50	3.30
.....	3.00	2.81	3.25	3.51	3.91
.....	none	none	none	trace	trace
.....	2.04	1.40	1.29	1.99	.59
.....	.07	trace	.02	.06	.03
.....	.03	.....	.....	.....	.....
	100.28	100.33	100.09	100.30	100.13

ORES OF IRON AND MANGANESE.

Iron ore from land of William Tabb, 3 miles from Catherine Fur-
Spotsylvania County, Va.

[Analysis by J. Edward Whitfield.]

	A.
SiO ₂	4.97
Fe	53.39
Mn	.60
S	.09
P	.66

Iron ore, Church Mountain Mine, Rockingham County, Va.
Manganese ore, same locality.

[Analyses by F. W. Clarke.]

	B.		C.
Ignition	12.78	Ignition	11.30
Insoluble	12.70	Insoluble	22.11
Fe	43.60	Fe ₂ O ₃ , Al ₂ O ₃	5.14
Mn	8.45	Mn	39.20
S	none	Co	2.48
P	.14		

The manganese ore contains no manganese dioxide. Its high percentage of cobalt is noteworthy.

D. Iron ore. Ridge north of Clinch River, 5½ miles above Stock creek, near and just west of Peckover Mill, Wise County, Va.

[Analysis by T. M. Chatard.]

	D.
SiO ₂	14.75
Fe	48.97
MnO	.12
S	.83
P	.067

E. Eastern extension of Cranberry bed, three-fourths mile east of Cranberry Creek, Mitchell County, N. C.

F. Western extension of Cranberry bed, Hardy Graves' tract, one-fourth mile southwest of Elk Park, Mitchell County, N. C.

Both samples are magnetite.

[Collected by J. R. Procter. Analyzed by T. M. Chatard.]

	E.	F.
SiO ₂	25.27	27.65
Fe	45.43	42.77
MnO	.54	.59
S	.07	.03
P	.009	.007

G. Iron ore. Northwest part of Sevier County, Ark.

H. Manganese ore. Southwest part of Polk County, Ark.

[Analyses by J. Edward Whitfield.]

	G.	H.
SiO ₂	12.01	4.80
Fe	42.85	11.36
Mn	6.59	13.95
S	.11	.....
P	1.48	.....
Ti	trace	.....

The manganese ore contains little dioxide.

I. Two samples iron ore, from Atalla, Ala.: *a*, from outcrops; *b*, 250 feet below surface.

[Analyses by R. B. Riggs, as called for.]

	A.	B.
Fe	57.52	7.75
CaO	1.38	47.64
CO ₂	.30	34.90

J. Iron ore. Farm of C. J. Garrison, Russ County, Tex.

[Analysis by J. Edward Whitfield.]

SiO ₂	14.53
Fe	48.56
S	.41
P	.405

COALS.**A. Lignite. Near light-house, Gay Head, Martha's Vineyard, Mass.**

[Collected by N. S. Shaler. Analysis by J. Edward Whitfield.]

Moisture	10.25
Volatile hydrocarbons	43.09
Fixed carbon	34.90
Ash	11.76
	100.00

Ash red. Coal burns well, but is very friable.

B. McNew coal bank, Powell's Mountain, Scott County, Va.**C. Horton mine, south side Powell's Mountain, near base, Scott County, Va.****D. Bear-pen branch, Chimney Rock fork of Stony Creek, Scott County, Va.****E. Hogan's cannel coal. East fork of Staunton Creek, Scott County, Va.****F. Coke from C.**

[Collected by J. R. Procter. Analyses B, C, D, E, by F. W. Clarke; F, by W. F. Hillebrand.]

	B.	C.	D.	E.	F.
Moisture	1.92	1.19	1.29	.39	.35
Volatile hydrocarbons	33.42	33.74	30.36	37.15	.....
Fixed carbon	55.62	58.92	63.27	42.05	91.36
Ash	9.04	6.15	5.08	20.41	8.29
	100.00	100.00	100.00	100.00	100.00
Coke	Good	Good	Good	Good	S... .68
Ash	Reddish	Reddish	.....	.....	P.. .034

G. Burnet County, Tex.

[Analysis by J. Edward Whitfield.]

Moisture	3.72
Volatile hydrocarbons	42.27
Fixed carbon	39.41
Ash	14.60
	100.00

Ash, dark gray. Coke poor, dark, and friable.

IRON AND STEEL.

[Two samples, analyzed by J. Edward Whitfield for the Ordnance Corps, U. S. A.]

A. Sample from a Gruson chilled cast iron armor plate, tested by the Italian Government at Spezia, April 20-29, 1886.**B. Hardened steel from 43-cm. Krupp shell, fired at Gruson plate "A," April 29, 1886.**

	A.	B.
Fe.....	93.91	98.00
Mn.....	1.75	.46
Ni+Co.....	.58	.12
Al.....	trace	.38
Ca.....	.20	.....
Si.....	.86	.23
P.....	.31	.02
S.....	.14	.04
Graphitic C.....	.81	.03
Combined C.....	2.04	.88
	100.60	100.16

NITRE FROM UTAH.

[Analysis by T. M. Chatard.]

	As found.		Probable combination.
Insoluble.....	12.12	Insoluble.....	12.12
H ₂ O.....	1.24	H ₂ O.....	1.24
SiO ₂ , Al ₂ O ₃	.20	SiO ₂ , Al ₂ O ₃	.20
CaO.....	1.43	NaCl.....	.08
MgO.....	trace	CaSO ₄	3.48
Na.....	.03	NaNO ₃	.33
Cl.....	.05	KNO ₃	82.47
SO ₃	2.05		
K ₂ O.....	38.38		99.92
Na ₂ O.....	.12		
N ₂ O ₅	44.30		
	99.92		

SALT FROM WARSAW, N. Y.

["Crescent Fine" brand, made from local brine. Analysis by T. M. Chatard.]

	As analyzed.		Probable combination.
H ₂ O.....	1.590	H ₂ O.....	1.59
Insoluble { CaSO ₄	.008	Insoluble.....	.17
{ Al ₂ O ₃	.080	CaSO ₄	.75
{ SiO ₂	.082	CaCl ₂	.45
SiO ₂	.003	MgCl ₂	.11
Al ₂ O ₃	.006	NaCl.....	97.34
CaO.....	.487		
MgO.....	.040		100.41
SO ₃	.442		
Cl.....	59.370		
Na ₂ O.....	51.410		
	113.518		
Less oxygen.....	13.380		
	100.138		
Needed, soda, to satisfy acids.....	.272		
	100.410		

TWO CLAYS FROM SHORE OF OWEN'S LAKE, CAL.

[Collected and analysed by T. M. Chastard.]

	Sandy clay.	Blue clay.
H ₂ O expelled at 110°	1.41	2.05
H ₂ O expelled at red heat	2.73	2.40
CO ₂	8.75	7.24
SiO ₂	53.24	54.92
TiO ₂	.25	.30
Al ₂ O ₃	10.84	11.25
Fe ₂ O ₃	2.59	2.77
FeO	.77	.94
MnO	.10	.08
CaO	9.18	8.76
MgO	5.82	4.91
K ₂ O	2.64	2.77
Na ₂ O	2.06	2.10
SO ₃	.08	trace
Cl	.05	trace
	100.51	100.49
Soluble in water	1.26	

CLAY, SAND, ETC., FROM MARTHA'S VINEYARD, MASS.

[Collected by N. S. Shaler. Partial analyses, as called for.]

- A. Average sample of white clay, east end of Chilmark cliffs.
- B. Average sample of clay, north end of Gay Head cliffs.
- C. Sandy white clay, south end of Gay Head cliffs.
- D. Average sample of southermost red clays, Gay Head.
- E. Average sample of fine white clay, south end of Gay Head cliffs.
- F. Average sample of fine clay and soil, east end of Weyquosque cliffs.
- G. Brown clay, 300 feet south of light-house, Gay Head.
- H. Average sample of red clay from the greensand, north end of Gay Head.
- I. Average sample of clays, Weyquosque series, Chilmark cliffs.
- J. Pyritiferous clay, central part of Gay Head section.
- K. Clay containing pyrite, west end of Chilmark cliffs.

[Analyses by F. W. Clarke.]

	A.	B.	C.	D.	E.
Ignition	3.47	11.47	10.79	9.83	6.36
SiO ₂	82.95	49.19	56.19	57.50	73.46
Al ₂ O ₃ , Fe ₂ O ₃	13.45	39.77	30.65	31.21	19.06
CaO	none	none	none	.19	none
MgO	trace	trace	trace	.20	trace
Na ₂ O					.70
K ₂ O				.40	.73
SO ₃			2.45		none
P ₂ O ₅	none	none	none	none	none
	99.87	100.43	100.08	99.33	100.31

	F.	G.	H.	I.	J.
Ignition.....	3.39	7.57	9.98	5.76	5.69
SiO ₂	70.81	56.62	55.93	61.76	72.74
Al ₂ O ₃ , Fe ₂ O ₃	20.67	31.24	33.51	25.35	21.46
CaO.....	trace	trace	none	.51	none
MgO.....	1.99	1.97	.19	1.95	trace
Na ₂ O.....	1.23	.40	undet	1.83	.....
K ₂ O.....	1.67	2.76	undet	3.01	.....
SO ₃.....	.....	.....	.....	.....	.....
P ₂ O ₅	none	none	none	trace	none
	99.76	100.56	99.61	100.17	99.89

	K.
SiO ₂	47.76
Al ₂ O ₃ , Fe ₂ O ₃	30.93
FeS ₂	7.27
SO ₃	.43
CaO.....	none
MgO.....	.38
K ₂ O.....	1.17
Na ₂ O.....	undet
H ₂ O.....	undet
P ₂ O ₅	trace

L. Average sample of phosphatic nodules from the greensand, north end of Gay Head cliff.

M. Average sample of fossil bones, Gay Head.

N. Greensand, northernmost exposure, Gay Head.

O. Greensand, north end of Gay Head.

P. Average sample of white sand, Gay Head section.

[Partial analyses by R. B. Riggs.]

	L.	M.	N.	O.	P.
SiO ₂	17.82	.....	.....	.....	78.69
Al ₂ O ₃.....	.....	.....	.....	.....	15.04
Fe ₂ O ₃.....	.....	.....	.....	.....	.60
CaO.....	25.73	27.21	1.09	.65	trace
MgO.....	.....	.....	.....	.....	undet.
Na ₂ O.....	undet. .15 {	.56	.38	.33	.19
K ₂ O.....		.97	3.87	4.16	1.09
CO ₂	2.60	3.28	.16	.14	.....
P ₂ O ₅	23.88	27.80	.48	.22	.....

WATER FROM PARIS, ME.

[From a large spring on the farm of William E. Cooper. Analysis by F. W. Clarke. Stated in grammes per liter.]

	Found.	Per cent. of total solids.	Hypothetical combination.	
SiO ₂	0.0170	2.64	SiO	0.0170
SO ₄	.3696	57.41	K ₂ SO ₄	.0027
CO ₃	.0754	11.71	Na ₂ SO ₄	.0609
Cl	trace	.....	CaSO ₄	.4440
K	.0012	.19	CaH ₂ (CO ₃) ₂	.0206
Na	.0262	4.07	MgH ₂ (CO ₃) ₂	.0391
Ca	.1357	21.08	MgCO ₃	.0328
Mg	.0158	2.45	FeH ₂ (CO ₃) ₂	.0067
Fe	.0021	.33		
H (bicarbonate)	.0008	.12		0.6438
	0.6438	100.00		

WATERS FROM SAVANNAH, GA.

[Partial analyses by R. B. Riggs. Stated in parts per million.]

- A. Savannah River, taken at high water, August 17, 1886.
 B. Savannah River, taken at low water, August 17, 1886.
 C. Artesian well adjoining water-works.

	A.	B.	C.
Cl	trace	trace	7.3
Free NH ₃	none	none	none
Albuminoid NH ₃	2.6	1.0	none
Inorganic solids	45.0	40.0	174.0
Organic solids	22.0	15.0	.....

The inorganic solids in C consist mostly of carbonates.

ARTESIAN WELLS IN GEORGIA AND ALABAMA.

[Partial analyses by R. B. Riggs. Stated in parts per million.]

- A. At Albany, Ga.
 B. At Smithville, Ga.
 C. At Americus, Ga.
 D. At Montezuma, Ga.
 E. At Fitzpatrick's, Ala.

	A.	B.	C.	D.	E.
Total solids	181.0	140.0	177.0	111.5	271.0
CO ₂	96.5	65.0	74.0	42.0	93.0
SO ₃	9.2	17.1	5.6	6.3	38.6
SiO ₂	27.0	13.0	43.6	26.2	40.8
Al ₂ O ₃	1.0	trace	trace	trace	2.4
CaO	21.8	6.4	48.4	11.2	19.8
MgO	1.2	.2	.5	.14	1.6

Examined with reference to use in steam-boilers. Chlorides and alkalis undetermined.

Found.	Per cent. of total solids.	Hypothetical combination.		
SiO ₂	0.160	2.25	SiO ₂	.0160
K.....	.0024	.35	KCl.....	.0046
Na.....	.0156	2.20	NaCl.....	.0072
Ca.....	.1350	19.03	Na ₂ SO ₄	.0395
Mg.....	.0361	5.09	CaSO ₄	.3620
Cl.....	.0066	.93	CaH ₂ (CO ₃) ₂	.1153
CO ₃	.2127	29.99	MgH ₂ (CO ₃) ₂	.0900
SO ₄	.2822	39.79	MgCO ₃	.0746
H ₂ (bicarbonate)....	.0026	.37		
	.7092	100.00		.7092

WATER FROM OWEN'S LAKE, CALIFORNIA.

[Analysis by T. M. Chatard. Stated in grammes per kilo. Sp. gr. 106246, 16°.5.]

	Found.	Per cent. of total solids.	Hypothetical combination.
Na	26.837	36.95	KCl..... 2.957
K.....	1.548	2.13	NaCl..... 27.694
Al ₂ O ₃	.023	.04	Na ₂ SO ₄ 10.443
Fe ₂ O ₃	.013	.02	Na ₂ B ₄ O ₇ 438
Ca	.014	.02	Na ₂ SiO ₃ 464
Mg.....	.005	.01	Na ₂ CO ₃ 26.319
SO ₄	7.060	9.71	NaHCO ₃ 4.233
Cl.....	18.215	25.07	CaCO ₃ 035
Br, I, H ₂ S.....	none	.....	MgCO ₃ 013
CO ₂	18.266	25.15	Al ₂ O ₃ 023
B ₂ O ₃	.339	.47	Fe ₂ O ₃ 013
SiO ₂	.262	.36	
H ₂ (bicarbonate)...	.050	.07	
	72.631	100.00	72.632

INDEX.

A.		Page.			Page.
Albany, Ga., water from.....		91	Devil's Head Mountain, Colo., minerals from.....		48
Alexander County, N. C., mica from.....		13	Diller, J. S., microscopic notes by.....	13, 15, 18, 28, 36, 53	
	tourmaline from.....	28	E.		
Allen County, Ky., meteorite from.....		64	Erinite.....		40
American Eagle Mine, Utah, minerals from.....		38	F.		
Americus, Ga., water from.....		91	Feldspars.....		79
Antlerite.....		55	Fitzpatrick's, Ala., water from.....		91
Antler Mine, Ariz., mineral from.....		54	Flow of solids.....		67
Artesian well waters.....		91	Fort Wingate, N. Mex., water from.....		92
Atalla, Ala., iron ore from.....		86	G.		
Anburn, Me., alteration product from.....		25	Gay Head, Mass., clays, etc., from.....		89
	mica from.....	16		lignite from.....	87
	tourmaline from.....	23	Gouverneur, N. Y., tourmaline from.....		26
Aznite.....		60	Greylock Mountain, Mass., feldspar from.....		79
B.			H.		
Baltimore, Md., mica from.....		14	Haddam, Conn., tourmaline from.....		29
Bergen Hill, N. J., datolite from.....		59	Hallock, William, on flow of solids.....		67
Beryl.....		16	Hamburgh, N. J., tourmaline from.....		26
Biotite.....		16	Hancock, Md., sandstone from.....		80
Brazil, tourmalines from.....		23	Hebron, Me., mineral from.....		25
Brochantite.....		46	Hillebrand, W. F., analysis by.....	40, 41,	
Burnet County, Tex., coal from.....		87		45, 49, 52, 53, 54, 55, 82, 84, 87	
Butte, Mont., mineral from.....		53		copper minerals from.....	
C.				Utah.....	38
California, rocks from.....		84		mineralogical notes.....	48
Chalcophyllite.....		43	Hisingerite.....		14
Chatard, T. M., analyses by.....	83, 84, 86, 88, 89, 93		Hoosac Tunnel, feldspar from.....		79
Church Mountain Mine, Va., ore from.....		85	Hot Springs, Ark., waters from near.....		92
Clarke, F. W., analyses by.....	13, 14, 15, 17, 18, 80, 86,		I.		
	87, 89, 91, 92		Iron, analysis of.....		88
	studies in the mica groups.....	13	Iron mica.....		16, 17
Clays, analyses of.....	89, 90		Iron ores.....		85, 86, 87
Clinoclase.....		43	J.		
Coals, analyses of.....		87	Johnson County, Ark., meteorite from.....		63
Colemanite.....		56	L.		
Cornwall, axinite from.....		60	Lepidomelane.....	14, 15	
Curry County, Oregon, pricelte from.....		58	Limestone.....		80
Cyrtolite.....		52	Litchfield, Me., mica from.....		15
D.			Ludwigite.....		59
Danburite.....		60	M.		
Datolite.....		59	Mammoth Mine, Utah, minerals from.....		38
Dauphiny, axinite from.....		61	Manganese ores.....		86
Death Valley, Cal., colemanite from.....		56			
Defiance, Ohio, limestone near.....		86			
De Kalb, N. Y., tourmaline from.....		26			
Delaware, feldspars from.....		79			

	Page.		Page.
Martha's Vineyard, clays, etc., from	80, 90	S.	
lignite from	87	Salt	88
Menomonee River, rocks from	81	Samarskite	48
Mica group	13	Sandstone	80
Mitchell County, N. C., iron ores from	86	Savannah, Ga., waters from	81
Mixite	45	Scorodite	66
Monroe, Conn., tourmaline from	27	Scott County, Va., coals from	87
Montana, rocks from	83	Sevier County, Ark., iron ore from	86
Montezuma, Ga., water from	91	Smithville, Ga., water from	81
Morawitz, ludwigite from	59	Solids, behavior under pressure	75
Muscovite	13	Spotsylvania County, Va., iron ore from	66
		Steel, analyses of	88
N.		Stony Point, N. C., mica from	13
Nantic Gulf, tourmaline from	28	tourmaline from	28
Nitre	88	T.	
O.		Tintic district, Utah, minerals from	38
Olivenite	39	Titanic oxide, new form of	38
Orford, N. H., tourmaline from	27	Tourmaline	19
Owen's Lake, Cal., clays from	89	Tyrolite	41
water from	93	U.	
P.		Ulexite	58
Pandermitte	58	Utah, minerals from	38
Paris, Me., tourmaline from	24	nitro from	88
water from	91	W.	
Pearce, R., analyses by	40, 41, 45, 53	Warsaw, N. Y., salt from	88
Pharmacosiderite	46	Washington, H. S., colemanite	87
Pierrepont, N. Y., tourmaline from	28	copper minerals	38
Pigeon Point, Minn., rocks from	81	Whitfield, J. E., analyses by	57, 58,
Polk County, Ark., ore from	86	59, 60, 61, 63, 64, 65, 80, 82, 85, 86, 87	
Priceite	58	on borates and borosilicates	58
R.		meteorites	63
Rhodes's Marsh, Nev., ulexite from	58	scorodite	65
Riggs, R. B., analyses by	24, 25	Wilmington, Del., feldspar from	80
26, 27, 28, 29, 30, 79, 80, 81,		Winslow, Me., beryl from	53
82, 83, 84, 86, 90, 91, 92		Wise County, Va., iron ore from	86
on tourmaline	19	Y.	
Rose Mine, N. Mex., mineral from	54	Yellowstone Park, scorodite from	65
Rumford, Me., tourmaline from	23		
Russ County, Tex., iron ore from	87		
Russell, N. Y., danburite from	60		

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 56



WASHINGTON
GOVERNMENT PRINTING OFFICE
1889

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

FOSSIL WOOD AND LIGNITE

OF THE

POTOMAC FORMATION

BY

FRANK HALL KNOWLTON



WASHINGTON
GOVERNMENT PRINTING OFFICE
1889

CONTENTS.

	Page
Letter of transmittal.....	9
Introduction.....	11
Value of the study of internal structure, with brief review of its progress.....	11
Geologic and geographic distribution of the Potomac formation.....	38
The organic remains and their mode of occurrence.....	39
Systematic description of lignite.....	41
Systematic description of silicified species.....	43
Cupressinoxylon Göppert.....	43
Cupressinoxylon pulchellum, n. sp.....	45
Cupressinoxylon McGeei, n. sp.....	46
Cupressinoxylon Wardi, n. sp.....	48
Cupressinoxylon Columbianum, n. sp.....	49
Araucarioxylon Kraus.....	50
Araucarioxylon Virginianum, n. sp.....	50



ILLUSTRATIONS.

	Page.
PLATE I. Lignite	54
II. Cupressinoxylon pulchellum, n. sp., a Cupressinoxylon McGeel, n. sp	56
III. Cupressinoxylon McGeel, n. sp	58
IV. Cupressinoxylon Wardi, n. sp., and Cupressinoxylon Columbi- anum, n. sp	60
V. Cupressinoxylon Wardi, n. sp., and Cupressinoxylon Columbi- anum, n. sp	62
VI. Cupressinoxylon Columbianum, n. sp	64
VII. Cupressinoxylon Columbianum, n. sp., and Araucarioxylon Vir- ginianum, n. sp	66



LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY, DIVISION OF PALEOBOTANY,
Washington, February 23, 1889.

SIR: I have the honor to transmit herewith the manuscript of a paper by Prof. F. H. Knowlton, Assistant Curator of Botany and Fossil Plants of the U. S. National Museum, on the Fossil Wood and Lignite of the Potomac Formation, and to request its publication as a bulletin of the U. S. Geological Survey.

Very respectfully yours,

LESTER F. WARD,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

FOSSIL WOOD AND LIGNITE OF THE POTOMAC FORMATION.

BY F. H. KNOWLTON.

INTRODUCTION.

VALUE OF THE STUDY OF INTERNAL STRUCTURE, WITH BRIEF REVIEW OF ITS PROGRESS.

The value of paleontology to stratigraphy is so generally recognized that it hardly needs to be emphasized. Heretofore, however, the evidence most relied on has been derived from a study of animal fossils, the reason being chiefly that there have been more paleozoölogists than paleobotanists and more data of a paleozoölogic character have been accessible. But paleobotany is gradually coming into prominence, and within the last half century, particularly within the last decade, it has shown a wonderfully increased development. Some of the most eminent botanists of the age have devoted their lives to the interpretation of this class of facts, and it has developed into an important department of natural science. Much, of course, remains to be done, particularly in this country, but when the plant deposits are as thoroughly explored as the animal deposits have been, stratigraphic geology will receive much valuable aid.

In paleobotany two distinct lines of investigation have been followed, which may be called respectively the superficial method and the structural method.

I use the term superficial, not in the sense that the evidence obtained by it is untrustworthy, but because it takes cognizance of the external or superficial parts of plants. It deals with the form and nervation of leaves, the scars and striations on the stems, and the casts or impressions of stems, leaves, and fruits. On account of the many conditions necessary for the successful preservation of vegetable remains, it most frequently happens that they are capable of being studied only by this method. Its legitimate application is seen in the monographs of Heer, Ettingshausen, Unger, and Lesquereux.

The structural method, on the other hand, deals with what must be regarded as the most valuable of all evidence—that derived from internal organization. Leaving out of view the superficial considerations, it concerns itself with a microscopical examination of the histological elements that enter into the composition of vegetable tissues. The vari-

ous tissue systems are dissected and carefully studied, the individual cells are measured and compared, and these, together with markings upon the cell walls and other like data, form a sure basis for the correct interpretation of the systematic position of plants. So valuable is this method that Prof. W. C. Williamson was led to say that "no determinations respecting fossil plants can have much absolute value save such as rest upon internal organization; that is the basis upon which all scientific recent botany rests, and no mere external appearances can outweigh the positive testimony of organization in fossil types."¹

The interest attached to this class of investigations has been greatly enhanced of late, and it has been no doubt largely due to modern improvements in instruments and methods of research, but also to an increased appreciation of their value. Certain it is that the number of students in this field is being constantly augmented. In order to show that the growth of this department has been both natural and constant, I append a brief résumé of its progress from the time of its first mention in literature down to the close of the year 1886. In the preparation of this bibliographic review I have been greatly aided by the historic summaries of the literature given by Dr. Göppert in his *Monographie der fossilen Coniferen*,² and by that of Prof. Lester F. Ward in his admirable "Sketch of Paleobotany."³ The former of these is particularly complete in the literature of the early or prescientific period, but closes, as indeed does the latter, with the year 1850. Consequently I have referred only briefly to the progress made prior to this date, but have aimed to make it as complete as space would permit for the time between 1850 and 1886.

It seems hardly probable, as Professor Ward has so pointedly suggested,⁴ that such common objects as pieces of petrified wood escaped all observation for the first twelve centuries of the Christian era; but, as the literature of that period contains no mention of them, we must suppose that public attention, at least, was not directed to the subject. That travelers and people engaged in agricultural pursuits must have observed them is more than probable, since fossil forests are now known to exist in northern Egypt, and plant beds have been found in Italy, Dalmatia, and other countries of the Roman Empire. This fact is not, however, without its parallel in other departments of learning, for it has been often shown that the ancients possessed a much more extensive and profound knowledge of nature than did any of the so-called learned men of the Middle Ages.

Probably the earliest published account of petrified wood is that

¹ On the organization of the fossil plants of the coal measures. Roy. Soc. London, Phil. Trans., vol. 161, part II, 1871, p. 492.

² Leiden, 1850. Pp. 71-166.

³ U. S. Geol. Surv., Fifth Ann. Rep., Washington, 1885, pp. 363-469.

⁴ Op. cit., p. 387.

given by Albertus Magnus¹ in the thirteenth century, although the first mention of it has been attributed to Agricola (1494–1555). The writers of this period, however, were concerned more with the processes of fossilization than with the affinity of the objects described. Thus Agricola supposed petrification to take place by penetration of a succus lapidescens into the tissues of plants and animals, and Kentmann² (1518–1568) described a process by which fossils could be produced artificially. Imperatus,³ Boyle,⁴ and Bromel⁵ likewise wrote of the process of fossilization, and Oerdes,⁶ Klein,⁷ and Matthioli⁸ in his letter to Bauhin also described specimens which came into their possession or expressed views concerning them.

The following writers, although principally interested in the origin of the fossils, actually described specimens. Agricola obtained what he supposed to be fossil ebony (Ebenholz) from Hildesheim. Gesner⁹ compared specimens which he obtained with the following living species: Fir (*Elatites*), alder (*Olethrites*), beech (*Phegites*), and oak (*Dryites*). Under the name of *Stelechites* he also described a stem which showed rudiments of branches. Albinus¹⁰ described a large birch from Krawewitz, in Bohemia.

The first book devoted entirely to the subject of fossil wood was published by Franciscus Stelluti, in Rome, in 1637, with the following title: "Trattato del legno fossile minerale nuovamente scoperto, nel quale brevemente si accenna la varia e mutabil natura di detto legno rappresentato con alcune figure che mostrano il luogo dove nasce, la diversità delle onde che in esso sive dono e le sue così varie e maravigliose forme." Stelluti recognized the resemblance between these and recent woods, but concluded that they differed so widely, in having neither roots nor branches, in burning with a clear flame and giving out more heat, and in other particulars, that it was impossible to suppose they had ever been living.

In the seventeenth century the writers and observers began to be more numerous. Thus we find Worman,¹¹ Robert Hook,¹² Balbinus,¹³

¹ Beati Alberti Magni de mineralibus Tractatus-I, Caput VII, Opera, Lugdani, 1651, vol. 2, p. 216.

² Nomenclatura rerum fossil., Tiguri, 1565.

³ Hist. natur. Neapel, 1599; Venedig, 1672; Cöln, 1695.

⁴ Exerc. de util. et præst. Phil. natur.

⁵ Lith. Svec: spec. 2. Cap. I, § III.

⁶ Valer. Cordi adnot. in Pedacii Dioscovid., etc., sylva qua rerum fossilium in Germania, etc., 1651.

⁷ Balhasar Klein mentioned in Göppert's Monographie der fossilen Coniferen, p. 73. I have not been able to consult the book directly.

⁸ Matthioli epistol. edit. Bauhini, Lugd., 1564.

⁹ Gesneri de rerum fossilium, lapidum. et gemmarum maxime figuris et similitudinibus liber, etc. Tiguri, 1565.

¹⁰ Meissenischen Land- und Bergchronik im 22. Tit., S. 170. Dresden, 1589.

¹¹ Museum. Wormian. Lugd. Batav., 1655.

¹² Micrographia, 1667.

¹³ Bohuslav Balbinus. Miscell. hist. regni Bohem. Prag, 1679.

Abbé de la Roque,¹ Westphal,² De la Hire,³ and John Morton⁴ all mentioning or describing specimens. Edward Lhwyd⁵ was the first to apply the term *Lithoxylon* to petrified wood. He seems also to have been the first to appreciate fully the value of paleontology to stratigraphy.

As the theories of fossilization had gradually succeeded and replaced one another (the generatio æquivoca of Aristotle, the vis lapidifica of Avicenna in the tenth century, and the virtus formativa of Albertus Magnus in the thirteenth century), so were they supplanted in turn by the not less fanciful flood theory, which, strangely enough, seems to have been first propounded by Martin Luther.⁶ The idea that the plant and animal petrifications brought to light were the remains of the Noachian deluge and had been tossed about and mingled by the angry waters did not meet with immediate acceptance, so widespread had become the other delusive hypotheses. But gradually it began to find followers, and we note that Gesner, Imperatus, Woodward, and Lhwyd gave it credence. Its chief exponent, however, was Johann Jacob Scheuchzer, whose famous book, *Herbarium Diluvianum*, appeared in 1709.

Scheuchzer violently attacked all the other theories and brought forward such a mass of seemingly overwhelming evidence in support of the flood theory that the world was fairly taken by storm, and many years passed before those even who saw the fallacy in it dared to stem public opinion and break away from it.

In 1723 an edition of his work was published at Leyden, in which all the objects described in the edition of 1709 as well as in his *Museum Diluvianum*, were arranged according to the botanical system of Tournefort, which had appeared in the mean time. The fossil wood was arranged in the following manner:

CLASSIS XVIII.

Arbores et frutices floribus apetalis.

This included only a leaf and a piece of wood of *Fraxinus* and the wood of *Buxus*.

CLASSIS XIX.

Arbores et frutices floribus apetalis amentaceis.

This class embraced specimens which he considered to belong to *Ostrya*, *Quercus*, *Abies*, *Pinus*, *Betula*, and several leaves, fruits, and cones of the same.

¹ *Zodiacum medico gallicum* Gener., 1680. Part IV.

² J. Casp. Westphal. *ephem. nat. curios.* dec. II, an. VIII, 1689.

³ Académie Paris, *Mém.*, 1692.

⁴ Roy. Soc. London. *Phil. Trans.*, 1706.

⁵ Eynardi Luidii *Lithophylacii britannici ichnographia, sive lapidum aliorumque fossilium britannicorum singulari figura insignium* * * * *distributio classica.* Londini et Lipsiæ, 1699.

⁶ *Gründliche und erbauliche Auslegung des ersten Buchs Mosis.* Halle, 1739, vol. I, p. 176.

CLASSIS XXI.

Arbores et frutices foliis rosaceis.

Only a single specimen, "Frustum ligni tilie petrifactum."

PLANTÆ INCERTÆ.

Here were included the woods which could not be relegated to any of the other classes. This list was of course the larger, including more than one hundred and fifty miscellaneous examples, from various parts of the world, one even from the island of Antigua, in the West Indies. The term *Lithoxylon* was applied in a few cases (e. g., number 465, "*Lithoxylon nigricans in saxo arenario duriosi ex Agro Altorffino*," but generally they were simply called "*lignum fossile*."

To enumerate the multitude of writers who made mention of fossil wood, or described specimens of it, during the eighteenth century would be to expand this chapter far beyond the limits assigned to it.¹ We must confine our sketch from this time forth to those more important writers whose works mark distinct epochs in the progress of paleodendrology. A few of the principal writers are Volkmann,² Henkel,³ Schröter,⁴ and Walch.⁵

The era of true science then may be said to have begun with the opening of the nineteenth century. Escaping from the influence of the superstitions and dogmas of the Dark Ages the keynote was struck, and from this time on the progress was constant and rapid. The true origin and nature of fossils were explained, and once on the right track the energy of investigators was directed to an interpretation of the paleontological facts, even in the most distant parts of the globe, and the result has been to furnish a pretty correct and comprehensive view of the faunas and floras of the different ages of the world's history.

In rapid succession were published the works of Voigt⁶ (1807), who discussed the so-called *Psarolithes*, which he at first regarded as polyps; Weppen⁷ (1808), who described fossil wood from Europe, Siberia, and the East Indies; and Martin⁸ (1809), who described fossil trunks from Great Britain. In 1814 Kieser published his valuable "*Mémoire sur l'organisation des plantes*," in which, among other important

¹ See H. R. Göppert. *Monographie der fossilen Coniferen*, pp. 81-86.

² Georg Anton Volkmann. *Silesia subterranea*. Leipzig, 1720.

³ *Flora saturniana*, 1755.

⁴ *Lithographische Beschreibung von Ingolstadt und Dettwiz*. Jena, 1768.

⁵ *Die Naturgeschichte der Versteinerungen zur Erläuterung der Knorr'schen Sammlung*, etc. Nürnberg, 1768-1773.

⁶ Johann K. W. Voigt. *Kurze mineralogische Bemerkungen*. Leonhard's Taschenbuch für Mineralogie, erster Jahrgang, pp. 120-124.

⁷ J. A. Weppen. *Nachricht von einigen besonders merkwürdigen Versteinerungen und Fossilien seines Kabinetts*. Leonhard's Taschenbuch, vol. II, p. 178.

⁸ William Martin. *Petrificata Derbiensia*, or Figures and Descriptions of Petrifications Collected in Derbyshire. Wigan, 1809.

facts, he first pointed out the characteristic structure of coniferous wood and correctly explained the nature of the concentric circles or bordered pits which are to be observed on the walls of the wood cells. These pits or pores had been observed by Malpighi¹ and others as early as 1685, but their exact nature had remained unexplained. An important work on the origin and nature of amber, by Dr. J. F. John, of Cologne, appeared in 1816. He supposed the amber to have been produced by a species of pine which he concluded had become extinct. About this time appeared several works by Jakob Nöggerath² on certain upright trunks and other fossils of the Carboniferous age. In the two principal works of the year 1820, by Rhode³ and Schlotheim,⁴ only incidental mention is made of fossil wood, and then only from a consideration of external characteristics.

Passing rapidly over several minor English and American papers we come, in 1828, to the publication of what was unquestionably the most important work on fossil woods that had yet been published. This is the "*Commentatio de Psarolithis, Ligni Fossilis Genere*," published at Halle by Anton Sprengel. After reviewing carefully the literature of the subject and discussing the various theories of the nature of these organisms he established their undoubted vegetable character and described six species which he called *Endogenites*. The work, which is in Latin, is illustrated by a single plate. Says Professor Ward:⁵

The year 1828 is without question the most eventful one in the history of paleobotany, since it saw the issue of Brongniart's *Prodrome* and the commencement of his *Histoire des végétaux fossiles*, which, taken together as they belong, form the solid basis upon which the science has since been erected.

The year 1830 was remarkable for the appearance of two papers by Henry T. M. Witham which gave evidence of the high and permanent place this author was to occupy in the annals of paleobotany. These papers, although short, treated of some of the peculiarities of structure to be observed in the plants of the Carboniferous of England. These observations were supplemented and extended in his "*Observations on Fossil Vegetables, accompanied by Representations of their Internal Structure as seen through the Microscope*," which appeared in the following year. In this volume, which was quarto in size, he discusses at length the peculiarities of structure which he was able to make out by the study of thin sections of the silicified specimens under the micro-

¹ Marcelli Maphighi opera omnia. Lugd. Bat., 1687.

² Über aufrecht im Gebirgsgestein eingeschlossene fossile Baumstämme und andere Vegetabilien. Bonn, 1819.

Fortgesetzte Bemerkungen über fossile Baumstämme und andere Vegetabilien. Bonn, 1821.

³ J. G. Rhode. Beiträge zur Pflanzenkunde der Vorwelt. Breslau, 1820.

⁴ Baron E. F. von Schlotheim. Die Petrifactenkunde auf ihrem jetzigen Standpunkte. Gotha, 1820; Nachträge, Gotha, 1822.

⁵ Sketch of Paleobotany, in Fifth Annual Report U. S. Geol. Survey, Washington. 1885, p. 406.

scope. In the preparation of these thin sections he acknowledges his indebtedness to the kindness of Mr. William Nicol, of Edinburgh, who first brought the method to his attention. This new method, which is the one in use at the present time, worked a complete revolution in the study of petrified trunks, and from the appearance of this book the study of the internal structure of fossil plants may be said to date. These sections were made by first grinding a smooth surface on the specimen and cementing it with Canada balsam to a small piece of glass. As much as possible of the specimen was cut away, leaving a thin layer adhering to the glass, and this was ground down until it was thin enough to allow the light to pass through, when it was mounted permanently in Canada balsam. Witham examined in this way fossil coniferous, monocotyledonous, and dicotyledonous woods, which he compared with living forms, but did not venture to give names to them. This was left for his last and greatest work, which appeared in 1833.¹ In this work, after describing the localities in Great Britain from which his specimens were obtained and giving other information concerning them, he established four genera of fossil conifers, the first that had ever been described from considerations of internal organization alone. The new genera were: *Peuce* and *Pitus*, each with two species; *Pinites*, with five species; and *Anabathra*, with one species. A single species of *Lepidodendron* was also characterized. The organization of these plants was illustrated by sixteen plates, two of which were, however, devoted to living species, and considering the time at which these figures appeared they are remarkably good.

A work had been published a year previous to this time which had also done much to stimulate the study of internal structure. This was C. Bernhard Cotta's "*Die Dendrolithen in Beziehung auf ihren inneren Bau*," in which he attempted to "classify systematically and describe scientifically the various kinds of fossil wood that had been discovered." He studied the internal structure of specimens in his collection and described several new genera and species. While the illustrations in his book are inferior to Witham's, they are nevertheless sufficiently characteristic to be readily recognized.

Besides several shorter papers that appeared about this time by Pattinson,² Parkinson,³ and others, the year 1831 saw the beginning of Lindley and Hutton's great work, the "*Fossil Flora of Great Britain*." This work, which was not completed until 1837, was concerned principally with the superficial phase of the fossil flora, but contained never-

¹The Internal Structure of Fossil Vegetables found in the Carboniferous and Oölite Deposits of Great Britain, Described and Illustrated. Edinburgh, 1833.

²H. L. Pattinson. On the Fossil Trees found in Jefferies Rake Vein at Derwent Lead Mine in the County of Durham. *Phil. Mag. and Annals*, vol. 7, London, 1830, pp. 186-189.

³James Parkinson. *Outlines of Oryctology. An Introduction to the study of Fossil Organic Remains.* London, 1830. Fossil wood, pp. 21-33.

theless illustrations and remarks on three of the species of *Pinites* (*P. Brandlingi*, *P. Withami*, and *P. medullaris*) mentioned by Witham.

In 1833 William Nicol published his valuable "Observations on the Structure of Recent and Fossil Coniferae,"¹ which was the first systematic comparison of internal structure instituted between living and fossil species. He examined quite an extensive series of living conifers, which he illustrated in six plates accompanying the article, and pointed out some facts that must be observed in the study of fossil forms. He refers to the method of preparing thin sections, which was credited to him by Witham as his invention, and says that it was not original with himself, but derived from a Mr. Sanderson, a lapidary of Edinburgh. In the following year he published a second article,² in which he described fossil dicotyledonous wood from the island of Mull with conifers and dicotyledons from Egypt and Nubia, and conifers from the Cape of Good Hope. He did not, however, attempt to give names to anything examined from these localities.

We pass hastily over the period from 1835 to 1839, during which papers of some interest in this department appeared by Bronn,³ Gazlay,⁴ and others, and come to the publication of Brongniart's splendid memoir on *Sigillaria elegans*.⁵ Having obtained from the environs of Autun, Aix-la-Chapelle, and Werden some perfectly silicified fragments which showed on the exterior the leaf scars characteristic of this species, Brongniart was enabled to examine for the first time the internal organization of this interesting group of plants. After describing carefully his specimens of *Sigillaria elegans* he compared them with all the other Carboniferous species of which the structure was known. These he divided into three groups, according to the distribution of the vascular elements. As *Sigillaria elegans* showed undoubted evidence of exogenous growth it was placed by Brongniart among the Gymnosperms, a position which was further insisted upon in 1849 in his "Tableau des genres de végétaux fossiles." Although the conclusion as to the systematic position of this species has since been shown by Williamson, Zeiller, and others to be incorrect, the publication of this memoir was a long step towards a solution of some of the most difficult problems of the relations between Cryptogams and Phaenogams.

Although Witham, Nicol, and others had described the structure of fossil dicotyledonous woods, no one had ventured to name genera or

¹ Edinb. New Phil. Jour., vol. 16, 1833-34, pp. 137-158, pl. II-IV, pp. 310-314, pl. v.

² On the structure of some fossil woods found in the Island of Mull, Northern Africa, and on the Karoo Ground to the northeast of the Cape of Good Hope. Edinb. New Phil. Jour., Vol. 18, 1834-35, pp. 335-338.

³ Heinrich Georg Bronn. Lethæa geognostica. Stuttgart, 1835-'38.

⁴ Rev. Sayrs Gazlay. Notices of Fossil Wood in Ohio. Am. Jour. Sci., vol. 25, 1834, pp. 104-107.

⁵ Observations sur la structure intérieure du *Sigillaria elegans* comparée à celle des *Lepidodendron* et des *Stigmaria* et à celle des végétaux vivants. Mus. Hist. Nat., Paris, Archives, 1839, pp. 405-461, pls. xxv, xxxv.

species until Göppert,¹ in 1839, characterized his *Klædenia quercoides*, a genus which is now included under *Quercinium* of Unger.

Several short papers appeared in 1841 by Unger,² Göppert,³ and others.

During the year 1842 Kutorga, in a short paper on the paleontology of Russia,⁴ described three new species of fossil wood, two of which are from the Kupfersandsteine of Perm, the other from the Kreidegebirge of Don. They were *Peuce biarmica*, *Peuce tanaitica*, and *Pinites biarmicus*. Göppert in this year contributed a paper⁵ on the flora of the iron sands of Aachen, in which he made valuable suggestions in regard to the method of studying fossil wood. Recognizing the fact that little could be accomplished in the study of fossil forms without a thorough knowledge of the internal structure of living species, he made a very careful examination of more than one hundred living species, of conifers. These he arranged in four groups, viz: the *Pinus*, *Araucaria*, *Taxus*, and *Ephedra* forms, and briefly characterized each.

For the fossil Coniferæ of Aachen he adopted Witham's name *Pinites*, and described a single new species, *Pinites aquisgranensis*.

Another new species of *Pinites* (*P. gypsaceus*) was described in the *Flora der Gypsformation in Oberschlesien*.⁶

Göppert also published a paper⁷ on the Cycadaceæ, in which, after reviewing what he had before written on the subject, he monographed the order. Of the seventy-eight species known at that time, nine were characterized from the trunks, sixty-five from the fronds, and four from the fruit.

The year 1845 was remarkable for the production of three great works, besides numerous smaller papers. These were Corda's "*Beiträge zur Flora der Vorwelt*,"⁸ Göppert's *Amber-Flora*,⁹ and Unger's

¹ "Bemerkungen über die als Geschiebe im nördlichen Deutschland vorkommenden versteinerten Hölzer." *Neues Jahrb.*, 1839, pp. 518-521, pl. VIII B.

² Franz Unger. Ueber die versteinerten Hölzer des National-Museums zu Lintz. *Warte an der Donau*, August, 1841, pp. 497-499.

³ *Taxites scalariformis*, eine neue Art fossilen Hölzer. *Karst. Archiv. für Mineral.*, etc., vol. 15, 1841, p. 727, plate XVII, figs. 1-7.

⁴ Dr. S. Kutorga. *Beitrag zur Palæontologie Russlands*. *Russ. kais. mineral. Gesell., St. Petersburg., Verhandl.*, 1842, pp. 1-34, plates I-VI.

⁵ Fossile Pflanzenreste des Eisensands von Aachen, als zweiter Beitrag zur Flora der Tertiärgebilde. *Acad. Leop. car. Nat. cur. Acta*, vol. 19, 1842, pp. 137-160, plate LIV.

⁶ Ueber die fossile Flora der Gypsformation zu Dirschel in Oberschlesien, als dritter Beitrag zur Fl. d. Tertiärgebilde. *Acad. Leop. Car. nat. cur. Acta*, vol. 19, 1842, pp. 369-378, plates LXVI-LXVII.

⁷ Ueber die fossilen Cykadeen überhaupt, mit Rücksicht auf die in Schlesien vorkommenden Arten. *Schles. Gesell. f. Vater. Kult., Uebersicht*, 1842, pp. 114-142.

⁸ August Joseph Corda. *Beiträge zur Flora der Vorwelt*. Prag, 1845, pp. 1-128, plates I-LX.

⁹ G. C. Berendt. Die im Bernstein befindlichen organischen Reste der Vorwelt. Vol. I. Berlin, 1845. I. Abtheilung: Der Bernstein und die in ihm befindlichen Pflanzenreste der Vorwelt (by Dr. Göppert).

*Synopsis plantarum fossilium.*¹ Lack of space prevents a satisfactory analysis of these works, and I will simply say that the first in the list, by Corda, is a magnificent folio, illustrated by sixty plates, nearly all of which are devoted to internal structure. Göppert's *Amber-Flora* was a complete summary of the known facts relating to the origin of amber, and also an enumeration of all the plants detected in it. The amber he thinks was produced almost entirely by a single species of pine, which he called *Pinites succinifer*. Unger's *Synopsis* enumerated 1,648 species of plants, the total number known at that time.

In 1847 appeared Unger's "*Chloris Protogæa*,"² another magnificent work, containing characterizations of a considerable number of new genera of Dicotyledons. The genera that appear for the first time are *Ulmium*, *Fegonium*, *Quercinium*, *Betulinium*, *Acerinium*, and *Plataninium*, named for their resemblance to wood of *Ulmus*, *Fagus*, etc. Many fine figures illustrate the work.

Equally important was Endlicher's "*Synopsis Coniferarum*,"³ which also appeared in 1847. Of the 177 species mentioned nearly 60 are characterized from internal structure.

This hasty review closes the period from the origin of definite ideas concerning petrifications to the beginning of the year 1850, which is remarkable for the production of two of the most important works. These were "*Monographie der fossilen Coniferen*,"⁴ by Göppert, and "*Genera et species plantarum fossilium*,"⁵ by Unger.

Göppert's work was a most elaborate essay, filling 359 quarto pages and illustrated by 58 plates, more than half of which is devoted to internal structure. The first 67 pages of the work describe the living conifers, which he considers under the following heads: I. Historical review of our knowledge of the Coniferæ. II. Geographical distribution. III. Organography and anatomy. This last part is, for the student of internal structure, perhaps the most important, as here are passed in review all the terms used in the description of the external and internal parts, with special emphasis of those characters which are found to be of the most importance in the diagnosis of genera and species.

The part devoted to the fossil Coniferæ is likewise divided into several subdivisions. The first of these is a historic review of the study of fossil plants, particularly the conifers, from the first crude speculations of the ancients through the formative period of the Middle Ages to the scientific period of our own times. This part more

¹ Lipsia, 1845.

² *Chloris Protogæa*. Beiträge zur Flora der Vorwelt. Leipzig, 1847.

³ Stephen Endlicher. *Synopsis coniferarum*. Sangalli, 1847.

⁴ *Monographie der fossilen Coniferen*. Natuurkundige Verhandelingen van de Hollandische Maatschappij der Wetenschappen te Haarlem. Tweede Verzameling, 6^e Deel. Leiden, 1850.

⁵ *Genera et species plantarum fossilium*. Vindobonæ, 1850.

than any other shows the scholarly attainments of the illustrious author. He seems to have read everything that had even the most remote bearing upon the subject.

In the systematic part, which occupies pages 169-248, he follows the divisions of the fossil forms into four groups as proposed by himself in 1842. In the Cupressineæ he established the genus *Cupressinoxylon* and described under it 15 species. Of the Abietineæ he described 38 species of *Pinites*, 6 of which were new; 11 species of *Araucarites*; 2 of *Pissadendron* and 1 of *Protopitys*. Under the Taxineæ he enumerates 4 species of *Taxites* and 1 each of *Physematopitys* and *Spiropitys*. Of the Gnetaceæ none are characterized from internal structure.

In the last part are enumerated all the localities where fossil wood, beds of coal, etc., occur, with a statement of the geological horizon to which each belongs.

A careful analysis of Unger's "Genera et species" can not be attempted. It is sufficient to say that it contains descriptions of 2,421 species of plants, a great advance in knowledge over anything that had previously appeared.

Two interesting papers on the structure of palms were published by C. G. Stenzel¹ during the year.

For the next few years, while much material was published that was of general interest in paleobotany, nothing of special importance came out relating to the internal organization of plants. Most of the papers were systematic descriptions of the flora of various localities and contain only incidental mention of fossil wood. Of this character were the papers of Weber,² Göppert,³ Massalongo,⁴ and Mercklin.⁵

Göppert's "Beiträge zur Tertiärflora Schlesiens" ⁶ was of more importance, as it contains descriptions of several species of *Cupressinoxylon*, *Pinites*, *Physematopitys*, *Taxites*, and *Spiropitys*.

One of the first contributions to our knowledge of American deposits of lignite was that by Edward Hitchcock⁷ on the brown coal deposit in Brandon, Vt. No attempt at identification of species from study of structure was made except that a pine cone in connection with "pine lignite" is mentioned. Many figures of dicotyledonous fruits, which

¹De trunco palmarum fossilium. Inaug. diss. Vratislavie, 1850, pp. 1-18, plates 1, II. Zwei Beiträge zur Kenntniss der fossilen Palmen. Acad. Leop.-Carol. Nova Acta, vol. 22, Breslau, 1850, pp. 467-503, plates 51-53.

²C. Otto Weber. Die Tertiärflora der niederrheinischen Braunkohlenformation. Palaeontographica, vol. 2, Cassel, 1852, pp. 115-236, plates XVIII-XXV.

³Fossile Flora des Uebergangsgebirges. Acad. Leop.-Car. nat. cur. Nova Acta, vol. 22, Supplement, 1852, pp. 1-229, tab. I-XLIV.

⁴Synopsis palmarum fossilium. Natur.-Wiss. Verein Lotos, vol. 2, 1852, pp. 193-208.

⁵C. von Mercklin. Ueber fossiles Holz und Bernstein in Braunkohle aus Gishiginsk. Acad. Imp. Sc. St.-Petersbourg. Bull. Classe Phys. Math., vol. 11, pp. 81-93, pl. I.

⁶Palaeontographica, vol. 2, Cassel, 1852, pp. 257-282, plates XXXIII-XXXVIII.

⁷Description of a brown coal deposit in Brandon, Vermont, with an attempt to determine the geological age of the principal hematite ore beds in the United States. Am. Jour. Sc., 2d ser., vol. 15, 1855 pp. 95-104.

were afterwards identified and named by Lesquereux,¹ accompany the article

The first American investigations of the internal organization of fossil wood seem to have been made in 1854 by Dr. (now Sir) J. Dawson, who mentions² specimens from Prince Edward Island which exhibited on the wood cells the hexagonal disks characteristic of the Araucarian type. The specimens are described as being perfectly silicified trunks of trees, in some cases three feet in diameter; they are proportionately and slightly flattened. These were subsequently described by Dawson as species of *Dadoxylon*, but no identification is made in the paper.

In the same year, but of less importance, was a note³ by Dr. A. King on fossil trees in the coal rocks of Pennsylvania.

The year 1854 was particularly remarkable for the European activity manifested. C. G. Stenzel, in his "*Staarsteine*,"⁴ monographed the genus *Psaronius*, enumerating 18 species, and gave much valuable information regarding the structure and synonymy. The six plates all illustrate the internal structure. Göppert, in his *Tertiary Flora of Java*,⁵ described the deposit of fossil wood of that country and established three new genera (*Junghuhnites*, *Bradæa*, and *Miquelites*), each with a single species.

Unger, in his *Flora of Gleichenberg*,⁶ described several conifers and three species of dicotyledons, and Balfour⁷ wrote of the vegetable structure detected in the coal of Fordel, a subject which had since the time of Witham attracted great attention.

The most important publication during 1855 was that of Schmid and Schleiden, "*Ueber die Natur der Kieselhölzer*."⁸ It is divided into two parts: the first treats of the average chemical composition of silicified wood and the second is a systematic description of the fossil wood in the Grand Ducal Museum of Jena. Twelve species are enumerated.

¹Am. Jour. Sc., 2d ser., vol. 32, 1861, pp. 355-363. Also see Hitchcock's *Geology of Vermont*, vol. 2, pp. 712-718.

²On fossil coniferous wood from Prince Edward Island. Acad. Sc. Phil., Proc., vol. 7, 1854, pp. 62-64.

³Description of fossil trees in the coal rocks near Greensburgh, Westmoreland County, Pennsylvania. Acad. Sc., Phil., Proc., vol. 7, 1854, pp. 64-65.

⁴Ueber die Staarsteine. Acad. Leop. Car. Nova Acta, vol. 24, Jena, 1854, pp. 753-896, plates 34-40.

⁵Die Tertiärfloora auf der Insel Java, nach den Entdeckungen des Herrn Fr. Junghuhn beschrieben u. erörtert in ihrem Verhältnisse zur Gesamttflora der Tertiärperiode. S. Gravenhage, 1854.

⁶Die fossile Flora von Gleichenberg. K. Acad. wiss. Wein, Denkschriften, vol. 7, 1854, pp. 157-184, pl. I-VIII.

⁷J. H. Balfour. On certain vegetable organisms found in the coal of Fordel. Roy. Soc. Edinb., Trans., vol. 21, 1854, pp. 187-193, pl. II.

⁸E. E. Schmid und M. J. Schleiden. Ueber die Natur der Kieselhölzer. Jena, 1855, pp. 1-42, plates I-III.

ated, of which four are new conifers and four new dicotyledons, and three new genera established, each with a single species.

In the next year several notices appeared by American authors. One by George C. Schaeffer described¹ the structure of two specimens of wood from the Colorado Desert. The specimens were very well preserved and are undoubtedly dicotyledonous, as is also the specimen from Posuncula River described by Prof. W. J. Bailey.² No names are given in either case, but the specimens from Colorado are compared with figures of dicotyledons from Antigua given by Witham in his "Internal Structure of Fossil Vegetables."

Dawson also described and figured³ the internal structure of wood from the Devonian of Gaspé, Canada East. The specimens, he says, were collected by Sir W. E. Logan in 1844, and placed in the collection of the Canadian Geological Survey. No attempt is made by Dawson to name these fossils, but they were without doubt coniferous.

Richter and Unger contributed a valuable paper, "Beitrag zur Palæontologie des Thüringer Waldes,"⁴ in which the structure of Calamopteris, Calamopitys, Stigmara, Lepidodendron, Cladoxylon, Aporoxylon, etc., is illustrated.

From 1856 to 1860 many interesting papers were published, of which, limited space will allow only the briefest mention. Goldenberg⁵ monographed the Selaginæ and the Sigillariæ; Göppert⁶ describes briefly the fossil forests discovered by Möllhausen in New Mexico and named a single new species (*Araucarites Mœllhausianus*). Unger also contributed two valuable articles. In one of these he describes⁷ the petrified forests near Cairo and in other parts of Egypt. Several new species are characterized, among them *Nicolia Egyptiaca*, which was named in honor of William Nicol, who will be remembered as the contemporary of Witham. The other paper, "Ueber fossile Pflanzen des Süsswasser-Kalkes und Quarztes,"⁸ describes and figures the internal

¹ Description of the structure of the fossil wood from the Colorado Desert. U. S. Pac. R. R. Rep., vol. 5, 1856, pp. 338, 339, plate xii, figs. 3, 4.

² Letter from Prof. J. W. Bailey, describing the structure of the fossil plant from Posuncula River. U. S. Pac. R. R. Rep., vol. 5, 1856, p. 337, pl. xii, figs. 1, 2.

³ J. W. Dawson. Remarks on a specimen of fossil wood from the Devonian rocks (Gaspé sandstones) of Gaspé, Canada East. Am. Assoc. Adv. Sc. Proc., vol. 10, 1856, pp. 174-176, figs. 1-4.

⁴ R. Richter and F. Unger. K. Acad. Wiss. Wien, Denkschr., vol. 11, 1856, pp. 1-100, plates I-XIII.

⁵ Friedrich Goldenberg. Flora Sarrapontana Fossilis. Die Pflanzenversteinerungen des Steinkohlengebirges von Saarbrücken. Saarbrücken, 1855-57.

⁶ Ueber die von Möllhausen mitgebrachten Fragmente des Holzes aus dem versteinerten Walde. In Möllhausen's Tagebuch einer Reise vom Mississippi nach den Küsten der Südpaz. Leipzig, 1858, p. 492.

⁷ Der versteinerte Wald bei Cairo und einige andere Lager verkieselten Holzes in Aegypten. Sitz. K. Acad. Wiss. Wien, math.-nat. hist. Kl. vol. 33, 1858, pp. 209-233, plates I-III.

⁸ F. Unger. K. Acad. Wiss. Wien, Denkschr., vol. 14, 1858, pp. 1-38, plates I-v.

structure of species of *Arando*, *Nymphaea*, *Thaloxylon*, *Betalinium*, *Klippsteinia*, *Peuce*, and *Hauera*. The species are all European, with the exception of *Hauera Americana*, which is from Papantla, Mexico.

In 1859 Dawson again returned to the study of the plants of the Peninsula of Gaspé, Lower Canada, and for the first time made positive determinations of them.¹ He visited Gaspé in person and collected an extensive series of specimens, upon which he founded several new genera and species. The first of these is *Psilophyton*, a genus of lycopodiaceous plants, "which is characterized by slender, bifurcating, ridged stems, proceeding from a horizontal rhizoma, which sends forth numerous rootlets." The internal structure had in most cases disappeared; yet it could be traced in a few instances. It is described as consisting "of a slender axis of scalariform vessels, surrounded by a space now occupied by calspar, but showing in parts the remains of a loose, cellular tissue. Externally to this is a cylinder of well preserved, elongated, woody cells, without distinguishable pores, but with traces of very delicate spiral fibers." Two species are established.

Prototaxites is described as a new genus of conifers in the following manner: "Woody trunks, with concentric rings of growth and medullary rays. Cells of pleureenchyma scarcely in regular series, thick walled and cylindrical, with a double row of spiral fibers. Disk structure indistinct." Coming, as this plant does, from the Devonian, it was regarded as one of the oldest forms of coniferous structure known, and yet it was highly differentiated even then, as is shown by the fact that its nearest living representatives were thought by Dawson to be *Taxus* and *Torreya*. Other remains of tissues, doubtfully referred to Unger's *Aporoxylon*, may represent a still more primitive phase.

In the same year was published a further contribution by the same author on the vegetable structures in coal,² the observations applying to the bituminous coal of Nova Scotia. He divides the coal into two classes: mineral charcoal and compact coal. In the mineral charcoal he detected both cryptogamous and gymnospermous tissue. In the former were abundant remains of scalariform tissues belonging apparently to *Lepidodendron*, *Ulodendron*, *Stigmaria*, and even *Sigillaria*. Of the gymnospermous tissues the identifications were less positive, although they were unquestionably coniferous and probably belonged to the Araucarian type.

Of the structure observed in compact coal comparatively little could be satisfactorily made out, although fragments apparently of both cryptogams and conifers were detected in exceptionally well-preserved specimens.

¹ On Fossil plants from Devonian Rocks of Canada. *Quart. Jour. Geol. Soc.*, vol. 15, 1859, pp. 477-478, figs. 1-6; also, *Can. Nat. and Geol.*, vol. 5, 1860, pp. 1 14, figs. 1-6.

² On the Vegetable Structures in Coal. *Quart. Jour. Geol. Soc.*, London, vol. 15, 1859, pp. 626-641, pl. xvii.

In 1861 there appeared an important work by Dr. F. Hildebrand,¹ in which he discusses in a very exhaustive manner the distribution of both living and fossil Coniferæ. The geological, as well as the geographical, distribution of the fossil species was given and has been of great aid to the student of stratigraphy. Several maps and tables illustrate the paper.

Curious remains of plant structure, identified as *Araucarites Schrollianus*, were detected by Bornemann² in quartz crystals.

The study of American material was carried on with great vigor by Dawson, who contributed numerous articles touching more or less upon the internal organization of the plants of Devonian and Carboniferous ages in Canada, Nova Scotia, and other regions. One, in 1861, "On the Pre-Carboniferous flora of New Brunswick, Maine, and Eastern Canada,"³ contains descriptions of species of *Dadoxylon*, *Prototaxites*, *Sternbergia*, *Aporoxylon*, etc., but a more elaborate and systematic paper than he had published up to this time was that on the "Flora of the Devonian Period in Northeastern America,"⁴ which appeared in 1862. In this he first discusses the localities in New York, Maine, Canada, and New Brunswick from which Devonian fossils have been obtained. In the systematic portion which follows, no less than 69 species belonging to 32 genera are described, of which number 36 species are regarded as new. Most of these are, of course, described from stem, leaf, or fruit impressions; but a few are characterized from internal structure, among them *Syringoxylon*, a new dicotyledonous genus. The single species known is from the upper part of the Hamilton Group, on Lake Erie. A new *Dadoxylon*, also from the same group, in Ontario County, New York, is described.

Among some of the shorter papers of this time may be mentioned one by Schimper,⁵ in which *Dadoxylon vogesiacum* is described as new, and one by Unger on some fossil plants from New Zealand.⁶ Two species of wood, *Podocarpium dacrydioides* and *Nicolia zelandica*, are mentioned by Unger. The first species of *Nicolia* it will be remembered was from the Egyptian Desert, and the occurrence of another species in New Zealand is of interest.

Göppert's "Flora of the Permian Formation,"⁷ which appeared at Cassel in 1864-'65, was another of the many valuable works produced by

¹ Die Verbreitung der Coniferen in der Jetztzeit und in den früheren geologischen Perioden. Bonn, 1861, 8°.

² J. G. Bornemann. Ueber Pflanzenreste in Quarzkrystallen. Deutsch. geol. Gesell., Zeitschr., vol. 13, Berlin, 1861, pp. 675-681, plate xvi.

³ Can. Nat. and Geol., vol. 6, 1861, pp. 161-180.

⁴ Quart. Jour. Geol. Soc., vol. 18, 1862, pp. 296-330, pl. xii-xvii.

⁵ Le Terrain de Transition des Vosges. Partie Paléontologique, par Wm. Ph. Schimper. Strasbourg, 1862, p. 342, plate xxx.

⁶ Fossile Pflanzen aus Neu-Seeland. In Hochstetter's Geologie von Neu-Seeland, Wien, 1864, pp. 1-13, plates i-v.

⁷ Die fossile Flora der permischen Formation. Cassel, 1864-'65.

this author. It contains 316 pages and 64 plates, not a few of the latter being devoted to internal structure. It is a systematic work, and describes and discusses with great fullness the 272 species that had at that time been collected from the Permian. Without attempting an exhaustive analysis, an idea of its magnitude and of the value to the student of the internal structure of fossil plants may be obtained by noting the number of species described from internal structure. There are 43 species of fern stems and rhizomes, of which number 25 belong to the genus *Psaronius* alone. The Cycadaceæ are represented by three species of *Zamites*, two species of *Medullosa*, and one species each of *Stenzelia*, *Myelopitys*, and *Colpoxylon*. The Coniferæ are represented by 16 species of *Araucarites* and a single species of *Pinites*. The work closes with a discussion of the origin and distribution of the Permian flora.

Another work of great value, also published in 1864, was the microscopical examination made by Kraus of the structure of living and fossil Coniferæ.¹ Wishing to ascertain, for use in the elucidation of fossil forms, what marks were of the most diagnostic value, he examined upwards of one hundred living species and obtained results which have been generally accepted. Without giving a full exposition an example will suffice. He investigated the width of the annual ring and found that it had no value as a distinctive mark, as it varied in different parts of the same individual and also widely from year to year, this latter variation being the result of changes in temperature and in moisture. In composition the ring consists of an inner, a middle, and an outer layer. The inner layer, or spring wood, consists of thin-walled, mostly four-sided cells, with bordered pits only on the radial walls; the middle layer, of thicker, mostly polygonal, cells, which have a decreasing radial diameter; the outer layer, or fall wood, is of thick-walled, compressed cells, with bordered pits on the tangential as well as on the radial walls. The predominance of certain layers may help to distinguish stem from root wood. Thus in the stem the cells of the inner layer predominate; in the root, the cells of the middle layer.

In similar manner were taken up the wood cells, resin cells and ducts, and medullary rays, and more or less valuable characters were drawn from them.

Equally useful observations were made on the fossil forms studied and several species new to science were diagnosed.

In 1863 Dawson described four new species of *Dadoxylon* from the coal formation in Nova Scotia.²

¹Gregor Kraus. "Mikroskopische Untersuchungen über den Bau lebender und vorweltlicher Nadelhölzer." Würzburger naturwiss. Zeitschr., vol. 5, 1864, pp. 144-200, plate v.

²Synopsis of the Flora of the Carboniferous Period in Nova Scotia. Montreal, 1864, pp. 1-27. Reprint from Can. Nat., 1863, vol. 8.

In the same year E. W. Binney published¹ a continuation of his observations on the structure of the coal plants of England. The specimens, eight in number, upon which these observations were made, were from the lower division of the coal measures of Lancashire and Yorkshire, and were embedded in calcareous nodules which occur in seams of coal. They were very perfectly preserved and yielded valuable results; but, as the author says in the conclusion, the memoir "was intended to be more of a descriptive character than an attempt to trace the analogy of the plants." They are, however, referred to *Diploxya* and *Sigillaria*.

Several short but valuable contributions appeared about this time from the pens of Unger,² Kraus, and others.

In one of these papers Unger reports the occurrence of *Nicotia Egyptiaca* from the highlands of Abyssinia. In another³ he characterizes two new genera of dicotyledons (*Constantinium* and *Tchihatcheffites*) from Thrace in Asia Minor.

Kraus, in his paper "Ueber einige bayerische Tertiärhölzer,"⁴ enumerates several well-known conifers and a new species of birch (*Betula lignitum*, and in his "Zur Kenntniss der Araucarien des Rothliegendes und der Steinkohlenformation,"⁵ he combined and characterized several species of *Araucarites*.

The year 1868 saw the completion of Eichwald's great work on the paleontology of Russia.⁶ This work, which was begun as early as 1859, consists of two parts, *Ancienne Période* and *Période Moyenne*, each accompanied by a folio atlas of plates, many of which are devoted to internal structure. It is impossible to give even an approximate analysis of the work, and we can simply say that it placed at the disposal of savants all the facts then known of the paleontology, animal as well as vegetable, of this vast empire.

This year was noteworthy also for the production of important papers by Cramer, Carruthers, Binney, Hooker, and others.

The "Fossile Hölzer der arctischen Zone,"⁷ by Cramer, deserves special mention. He describes and figures wood from Greenland, Barrow Land, and Spitzbergen, which, with one exception, was found to be coniferous. From Greenland came two species of *Cupressinoxylon*.

¹ A description of some fossil plants, showing structure, found in the Lower Carboniferous seams of Lancashire and Yorkshire. Roy. Soc. London, Phil. Trans., 1865, pp. 579-4 pls. xxx-xxxv.

² Notiz über fossile Hölzer aus Abyssinien. Wien, 1866, pp. 289-297, plate 1.

³ Flore tertiaire moyenne. In Tchihatcheff's *Asie Mineure*. Paris, 1866-'69, 4^e partie, pp. 319-325, pl. xvii, figs. 1-4.

⁴ Würzburger naturwiss. Zeit., vol. 6, 1866-'67, pp. 45-48.

⁵ Op. cit., pp. 70-73.

⁶ Édouard D'Eichwald. *Lethæa Rossica, ou Paléontologie de la Russie*. Stuttgart, 1853-'68.

⁷ Cramer. In *Flora fossilis arctica*. Oswald Heer. Vol. 1. Zürich, 1868, pp. 1-180, plates xxxiv-xliii.

Brevorni Merekl. and *C. uoranicum* Göpp.); from Banks Land, a single species of *Pinus* (*P. MacClurii* Heer), three species of *Cupressinoxylon* (*C. pulchrum* Cramer, *C. dubium* Cramer, and *C. polymmatum* Cramer), and the now well known *Betula MacClintockii*; from Spitzbergen came three species, all new, of *Pinites* (*P. latiporus*, *P. pauciporus*, and *P. cavernosus*).

Carruthers's paper on the Cycadean stems of Britain¹ was a valuable contribution to our knowledge of this poorly understood family. So, also, were Hooker's papers on the structure of *Stigmaria*² and on the structure and affinities of some *Lepidostrobi*.³

Binney issued in this year the first part of his "Observations on the Structure of Fossil Plants found in the Carboniferous Strata," a consideration of which is deferred.

The most systematic contribution to our knowledge of the fossil Coniferae published since Göppert's Monographie was that of Dr. Kraus, in Schimper's "Traité de Paléontologie Végétale."⁴ Ever since the publication of Göppert's work, "De Coniferarum structura anatomica," in 1841, the opinion had been growing among students that the genera must be regarded as comprehensive; that is, that a genus established upon fossil remains may include what might be regarded as several distinct genera, provided they were living and in possession of other organs which are of taxonomic value. With this point settled, Kraus divided the Coniferae into the five following types, which, it will be observed is one more than Göppert admitted:

I. Type of *Cupressinae* (*Cupressinoxylon*), comprising all the *Cupressinae*, the *Podocarpae*, and a part of the *Taxae*.

II. Type of the *Abietinae* (*Cedroxylon*), including the genera *Abies*, *Picea*, *Larix*, and *Cedrus*.

III. Type of the *Pinaceae* (*Pityoxylon*), which includes the genus *Pinus* and its subgenera.

IV. Type of the *Araucariaceae* (*Araucarioxylon*), which will include *Araucaria*, *Agathis*, etc.

V. Type of the *Taxae* (*Taxoxylon*), comprising all the genera not included under *Cupressinoxylon*.

Apoxylon Unger is still retained as a genus incertae sedis.

To these six generic types all the other names in use were reduced as synonyms. Thus *Cupressinoxylon* Kraus included *Thuioxylon* of Unger and Endlicher and *Physematopitys* of Göppert; *Araucarioxylon* Kraus was made to include *Araucarites* Göpp., *Pissadendron* Endl., and *Palaeoxylon* Brongn. Other changes it is unnecessary to mention.

¹ William Carruthers. On Fossil Cycadean Stems from the Secondary Rocks of Britain. Linn. Soc. Lond., Trans., vol. 26, 1868, pp. 675-708, pls. LIV-LXIII.

² On some peculiarities in the structure of *Stigmaria*. Geol. Surv., Gt. Brit. Mem., vol. 2, pt. 2, 1848, pp. 431-439, pls. I, II.

³ Remarks on the Structure and Affinities of some *Lepidostrobi*. *Op. cit.*, pp. 440-456, figs. 1-5 in text.

⁴ Bois fossiles des conifères. In *Traité de paléontologie végétale*, W. P. Schimper, vol. 2, Paris, 1870-'72, pp. 363-385, Atlas, pl. LXXIX.

This systematic arrangement was followed by a detailed enumeration without description of all the known species.

The period between 1870 and 1880 was a remarkably active one, as is shown by the fact that more than fifty papers, of greater or less value, appeared during this time. As it will be impossible to notice all these works fully a few only of the more important will be selected and the others given by title only.

Caruthers contributed an article on the fossil forests near Cairo,¹ in which he described and figured yet another species of *Nicolia*, named in honor of the collector, *N. Owenii*.

The wonderful fossil forests of California and the Yellowstone National Park were treated of in short articles, the former by Marsh² and the latter by Holmes.³ The structure of the specimens from California was investigated by Dr. M. C. White, of New Haven, and pronounced by him to resemble the wood of *Sequoia*, but no further attempt was made to determine it.

Specimens of the wood from Californian forests were later sent to Dr. H. Conwentz,⁴ in Breslau, who made a thorough examination, which resulted in determining them all to be coniferous and to belong to a single species, which he called *Cupressinoxylon taxodioides*.

The year 1871 saw the beginning of Professor Williamson's great work "On the Organization of the Fossil Plants of the Coal Measures." This work, published in the Transactions of the Royal Society of London, already (1889) numbers fifteen parts, and is, it is safe to say, the most valuable contribution that has been made to our knowledge of the organization of the plants of the Carboniferous age. A consideration of it is deferred.

This work by Professor Williamson is by no means his first, as he entered the field of paleontological science in 1833 as a contributor to the Fossil Flora of Great Britain, by Lindley and Hutton. From that time many able articles on the plants of the Coal Measures have appeared from his pen. They are mostly short and directly to the point. A chronological list of most of them is given below.⁵

¹ On the Petrified Forest near Cairo. Geol. Mag., vol. 7, 1870, pp. 306-310, pl. xiv.

² Notice of a Fossil Forest in the Tertiary of California. Am. Jour. Sci., 3d ser., vol. 1, 1871, pp. 266-263.

³ Fossil Forests of the Volcanic Tertiary Formations of the Yellowstone National Park. U. S. Geol. and Geog. Surv. Terr., Bull., vol. 5, No. 1, 1879, pp. 125-132.

⁴ Ueber ein tertiäre Vorkommen cypressinartiger Hölzer bei Calistoga in Californien. Neues Jahrb., 1879, pp. 800-813, plates XIII-XIV.

⁵ On the origin of coal. Brit. Assoc. Adv., Sc. Rep. 1842, Notices and abstracts, pp. 48-49.

On the structure and affinities of the plants hitherto known as *Sternbergiæ*. Lit. and Phil. Soc. Manchester, Mem., 2d ser., vol. 9, 1851, pp. 340-347.

Additional notes on the structure of *Calamites*. Lit. and Phil. Soc. Manchester, Proc. vol. 8, 1869, pp. 153-155.

On the structure of an undescribed type of *Calamodendron* from the upper

This period was one of greatest activity for Dr. J. W. Dawson, who published at least a dozen papers relating more or less to the organization of the fossil plants of Canada, Nova Scotia, etc. The most important are the following: "On the structure and affinities of *Sigillaria*, *Calamites*, and *Calamodendron*,"¹ in which he describes and figures very perfect examples of these forms, and presents a scheme of relationship; a paper on Prince Edward Island,² in which he mentioned two species of *Dadoxylon* (*D. materiarium* and *D. Edvardianum*), and characterized and illustrated them; and a note on the plants collected by Mr. G. M. Dawson near the forty-ninth parallel,³ in which is reported the occurrence of *Cedroxylon*, *Pityoxylon*, *Cupressoxylon*, *Taxoxylon*, and *Populus*.

In a collection of wood from the Mesozoic, British Columbia,⁴ made by Mr. Richardson, Dawson detected *Cupressoxylon* and *Taxoxylon* among the gymnosperms, and species of *Quercus*, *Betula*, and *Populus* among the angiosperms. Specific names are omitted in all instances.

In 1875 appeared the fourth and last part of Binney's "Observations on the Structure of the Fossil Plants found in the Carboniferous Strata,"⁵ a work which was begun, it will be remembered, in 1868. Each

Coal-Measures of Lancashire." Lit. and Phil. Soc. Manchester, Proc., vol. 2, 1869, pp. 26-37.

On the structure and affinities of some exogenous stems from the Coal-Measures. Monthly Mic. Jour., vol. 2, 1869, pp. 66-72.

On the structure of the woody zone of an undescribed Calamite (? *Calamopituis*). Lit. and Phil. Soc. Manchester, Mem., vol. 4, 1869, pp. 155-183.

On the organizations of the stems of *Calamites*. Brit. Assoc. Adv. Sc., Rep. 1870, Notices and abstracts, pp. 89-90.

Exogenous structures amongst the stems of the Coal Measures. Nature, vol. 4, 1871, pp. 490-492.

On the organization of an undescribed verticillate Strobilus from the lower Coal Measures of Lancashire. Lit. and Phil. Soc. Manchester, Proc., vol. 10, 1871, pp. 105-106.

On the structure of some specimens of *Stigmaria*. Lit. and Phil. Soc. Manchester, Proc., vol. 10, 1871, pp. 116-118.

On the structure of the woody zone of an undescribed form of Calamite. Lit. and Phil. Soc. Manchester, Mem., vol. 10, 1871, pp. 155-183.

On the structure of the *Dictyoxylons* of the Coal Measures. Brit. Assoc. Adv. Sc., Rep. 1871, Notices and abstracts, pp. 111-112.

On the fern-stems and their petioles, of the Coal Measures. Brit. Assoc. Adv. Sc., Rep. 1873, Notices and abstracts, p. 106.

¹ Quart. Jour. Geol. Soc., vol. 1871, pp. 147-161, pls. VII-X.

² Report on the Geological Structure and Mineral Resources of Prince Edward Island. Montreal, 1871, pp. 1-51, pls. I-III.

³ Note on the plants collected by Mr. G. M. Dawson, from the lignite tertiary deposits near the forty-ninth parallel. Report by G. M. Dawson, Montreal, 1875. Appendix, pp. 327-331, pls. XV-XVI.

⁴ Note on Fossil Woods from British Columbia, collected by Mr. Richardson. Am. Jour. Sc., 3d ser., vol. 7, 1874, pp. 47-51.

⁵ E. W. Binney. Palaeontographical Society, London. Observations on the Structure of Fossil Plants found in the Carboniferous Strata. Part I, vol. 21, 1868, pp. 1-32, pl. I-VI; Part II, vol. 24, 1871, pp. 33-62, pl. VII-XII; Part III, vol. 25, 1872, pp. 73-96, pl. XIII-XVIII; Part IV, vol. 29, 1875, pp. 97-147; pl. XIX-XXIV.

part is complete in itself and deals with one or more of the characteristic types of the Carboniferous flora. Thus the first part takes up *Calamites* and *Calamodendron*. After giving the bibliography, synonymy, and geological position of these types, a detailed and careful description is given of the specimens upon which the memoir is founded, and in conclusion the resemblances and the distinctions between *Sigillaria* and *Calamodendron* are pointed out. In a similar manner the other parts describe the structure and discuss, more or less, the affinity of *Lepidostrobus* and some allied cones, *Lepidodendron* and *Sigillaria*, and *Stigmaria*. This work was a most valuable contribution to our knowledge of some of the intricate problems connected with the origin and development of vegetation.

In 1876 Conwentz¹ published his first contribution to the study of fossil wood, in the form of an inaugural dissertation presented to the faculty of the University of Breslau. This work, which gave an earnest of his future position as a thorough worker, dealt with the wood of the North German Diluvium. He found both conifers and dicotyledons. Of the former he mentions three species, one new, for which he restores the generic name of *Pinites*. Of the Dicotyledons he obtained three species of oak, for which he adopts the name of *Quercites* of Göppert in place of the generally accepted *Quercinium* of Unger.

In the United States, Claypole² described a new fossil tree from the Clinton Limestone of Ohio, for which he proposed the name of *Glyptodendron*.

Renault published two elaborate memoirs³ on the structure of the plants of the Carboniferous, with the mention of which I close the enumeration of the publications of this decade.

In the next decade, beginning in 1880, a glance at the literature suffices to show that there is an ever increasing activity and interest in this branch of paleontological science. Discarding older and cruder ideas regarding the constitution of genera and species, a knowledge of what can and what can not be made out by a study of the preserved remains is accepted, and "hair-splitting subtleties" give place to deductions made on a firmer scientific basis.

Among such a wealth of publications it is difficult to select any for special mention, as all are, in one way or another, of so much value, but a brief enumeration of such as possess undoubted superiority or interest will be attempted.

Schroeter's⁴ examination of the fossil wood of the Arctic zone, made

¹ Über die versteinten Hölzer aus dem norddeutschen Diluvium. Breslau, 1876.

² E. W. Claypole. On the occurrence of a fossil tree (*Glyptodendron*) in the Clinton Limestone (base of Upper Silurian) of Ohio, U. S. Geol. Mag., vol. 5, 1878.

³ B. Renault et C. Grand'Eury. Études sur le *Sigillaria spinulosa* et sur le genre *Mylopteris*. Paris, 1875. Structure comparée de quelques tiges de la flore carbonifère. Mus. Paris, Nouvell. Archiv., pp. 313-348, pl. x-xvii, 1879. 2d Ser., vol. II.

⁴ Untersuchung über fossile Hölzer aus der arctischen Zone. In *Flora fossilis arctica*. Oswald Heer., vol. 6, Zürich, 1880, pp. 1-36, plates I-III.

in 1880, is more than a mere description of species; it is a valuable discussion of important structural points, particularly in the Coniferae. He accepts the classification of Kraus and gives an analysis of the five groups in seeking to identify a specimen from King Charles's Land, which is afterwards described as new, under the name of *Pinus Johnseni*. From the Mackenzie River three species are described, of which two are new, viz., *Sequoia Canadensis*, *Ginkgo spec.*, and *Platanus aceroides* Göpp.

In this year also Conwentz contributed an article on the wood of Karlsdorf,¹ in which he speaks at some length of the various collectors and writers who have worked upon material from this locality, which he regards as one of the richest deposits of fossil wood known.

After an examination of a large series of specimens the conclusion is reached that they all belong to a single form, for which the new generic name *Rhizocupressinoxylon* is proposed, since they are all considered as representing the wood of the roots. Conwentz thinks three specimens to be the roots of *Cupressinoxylon uniradiatum* of Göppert, and refers them to this species under his new genus. By this process, which has been justly condemned, we may have a single species known under two accepted, but totally different, generic names, depending upon whether the specimens examined be regarded as stem or root wood. This idea, if carried out, would create untold confusion, and make nomenclature an end rather than a means.

Numerous other smaller roots were found penetrating the tissues of *Rhizocupressinoxylon*, some of which were analogous to the roots of cypress, others to the roots of the alder. For these latter the name *Rhizoalnoxylon* is proposed, and one species is characterized.

The mycelium of a fungus was also found in the tissues of many of the specimens.

In the following year Dr. Conwentz worked up the fossil wood in the collection of the Royal Geological Land Office Department of Berlin.² Most of it was identified as coniferous, although a few dicotyledonous species were detected, among them a new genus, *Cornoxydon*, with two species. Two new species of *Fasciculites* are also characterized by Dr. Stenzel, of Breslau.

In the same year Göppert and Stenzel³ published their paper on the *Meduloseæ*, a new group in the *Cycadaceæ*, which they propose to take the place of the group to which the species of *Meduloseæ* were usually referred.

Undoubtedly one of the most important papers in 1882 was the "Studien über fossile Hölzer," by Johannes Felix, presented as an inaugural

¹Die fossilen Hölzer von Karlsdorf am Zobten. Danzig, 1880, pp. 1-47, plates I-VIII.

²Fossile Hölzer aus der Sammlung der königlichen geologischen Landesanstalt zu Berlin. Jahrb. d. k. preuss. geol. Landesanstalt, 1881, Abhand., pp. 144-171.

³Die Medulloseæ. Eine neue Gruppe der fossilen Cycadeen. Cassell, 1881, pp. 1-17, plates I-IV.

dissertation to the philosophical faculty of the University of Leipzig. It is a pamphlet of 81 pages and has one plate. The first part is a discussion of the characters found to be of most importance in distinguishing fossil genera and species. In dicotyledons and monocotyledons he considers that the genera must be in a measure comprehensive, while for the conifers he follows Kraus in adopting five types. In describing conifers, however, he falls into the grave error initiated by Conwentz (*supra*, p. 32) of using the prefixes rhizo-, cormo-, and clado-, to distinguish wood of the root, stem, and branch. In this way a single species may come to have three totally different generic appellations, and in anything but a systematic arrangement would be as widely separated as the initial letters will permit. Its absurdity is well shown on pages 46 and 47, when *Cupressoxylon Protolarix* of Kraus *Pinites Protolarix* (L.) is given under the names of *Cormocupressoxylon Protolarix*, *Cladocupressoxylon Protolarix*, and *Rhizocupressoxylon Protolarix*!

In the systematic part are described woods from Europe, India, Java, Japan, the Islands of Cuba and Antigua in the West Indies, from Brazil, and from Australia. About forty species are enumerated, nearly all of which are new.

Two short papers by Schenk also appeared in 1882. The first of these treats of the wood collected in India by the brothers Schlagintweit,¹ and the other is a discussion of Cotta's species of the genus *Perfossus*.² Cotta described two species (*P. angularis* and *P. punctatus*), the originals of which Dr. Schenk had opportunity of examining in the Dresden Museum. He found them to be unquestionably palm-like in structure and proposed the name *Palmoxylon* for them, a name which has been since adopted for all palm wood.

In a paper on the plants of the Erian (Devonian) and Upper Silurian formations of Canada,³ Dawson again defends his *Prototaxites* and affirms as his opinion that it is "a cotemporary of that prototype of gymnosperms *Aporoxylon* and similar plants of the Devonian," and has a decided likeness to the modern *Taxus* in structure. Of the genus *Dadoxylon* he describes one new species, which is the fifth reported from the Middle Erian of America, "an interesting confirmation," as he says, "of the facts otherwise known as to the great richness and variety of this ancient flora."

Other papers during this year were published by Felix,⁴ Beck,⁵ and others.

¹ Dr. A. Schenk. Die von den Gebrüdern Schlagintweit gesammelten fossilen Hölzer. Engler's bot. Jahrb., vol. 3, 1882, pp. 353-358.

² Die *Perfossus*-Arten Cotta's op. cit., pp. 483-486.

³ Geol. Surv. Canada, pt. 2. Montreal, 1882. Pp. 95-142, pls. XXI-XXIV.

⁴ J. Felix. Beiträge zur Kenntniss fossilen Coniferenbölzer. Engler's bot. Jahrb., vol. 3, 1882.

⁵ Richard Beck. Das Oligocän von Mittweida mit besonderer Berücksichtigung seiner Flora. Deut. geol. Gesell., Zeitschr., vol. 34, 1882, pp. 735-770, plates XXXI, XXXII.

The year 1883 witnessed the production of a goodly number of valuable contributions, mostly from well known authors.

Two by Felix are deserving of special notice. Under the modest title of "*Untersuchungen über fossile Hölzer*,"¹ he gives much useful information concerning Tertiary dicotyledonous woods. The genera mentioned are *Laurinoxylon*, *Lillia*, *Helictoxylon*, *Sapotoxylon*, *Quercinium*, and *Ficoxylon*. The discussion of the genus *Quercinium* is particularly interesting. In the second part of this paper material from other horizons is described, among which are roots of plants found penetrating other tissues. The name *Rhizonium* of Corda is adopted for these intruding roots except in one case, where it was clearly of the nature of a cypress, when it was called *Rhizocupressoxylon*, after Conwentz.

The other work by Felix is a monograph of the fossil wood of the West Indies.² In the introduction he again speaks of the difficulty attending a satisfactory determination of angiospermous wood as compared with that of gymnospermous wood, and concludes, after having examined over 400 living species, that the genera founded on fossil forms must be regarded as comprehensive. *Salicinium*, for example, will include wood of *Populus* as well as that of *Salix*.

Most of the material was from the Island of Antigua, from which fossil wood had been known since the time of Scheuchzer. The following genera of dicotyledons were identified: *Tenioxylon*, *Zittelia*, *Cassioxylon*, *Schmideliopsis*, *Anacardioxylon*, *Ebenoxylon*, and *Helictoxylon*. The monocotyledons all belong to the genus *Palmoxylon*, of which ten species are described and figured.

In 1883 also appeared the first volume of Göppert and Menge's magnificent "*Flora des Bernsteins*,"³ a work which neither of the illustrious authors lived to complete. The second volume was written by Dr. H. Conwentz, and appeared in 1886. The first volume is the most valuable to the student of internal structure, since it contains the results of the examination of the internal structure of such fragments of wood as were preserved in connection with the amber. Göppert first reviewed the work that had been done by Kraus on the structure of living conifers. Many species were described, some from characters taken from the wood, others from leaves, flowers, and fruits, all being illustrated by beautiful colored plates. In conclusion, an elaborate account is given of the origin and relations of the amber flora.

The fossil wood of the Libyan Desert, by Schenk,⁴ is a valuable

¹ *Dent. geol. Gesell., Zeitschr.*, vol. 35, 1883, pp. 59-91, plates II-IV.

² *Die fossilen Hölzer Westindiens. Sammlung palaeontologischer Abhandl., Ser. I, part I.* Cassel, 1883, pp. 1-32, plates I-V.

³ H. R. Göppert und A. Menge. *Die Flora des Bernsteins und ihre Beziehungen zur Flora der Tertiärformation und der Gegenwart.* Erster Band, Danzig, 1883; Zweiter Band, Danzig, 1886.

⁴ *Fossile Hölzer.* In *Beiträge z. Geol. u. Palaeont. d. libyschen Wüste und der angrenzenden Gebiete von Aegypten.* *Palaeontographica*, vol. xxx, 1883, pp. 1-20, plates I-V.

systematic paper. In it the conifers are represented by one species of *Araucarioxylon*; the monocotyledons by two species of *Palmoxylon*; the dicotyledons by the following genera, each, except the first, with a single species: *Nicolia*, *Acacioxylon*, *Rohlfisia*, *Jordania*, *Laurinoxylon*, *Capparidoxylon*, *Dombeyoxylon*, and *Ficoxylon*. These last, it will be seen, are mostly named from some living dicotyledon which they most nearly resemble.

In 1884 the most important contribution was that of Beust,¹ in which he describes and figures several species from the Lower Miocene of Greenland.

One of the new species *Araucarioxylon Heerii* is the first of the genus found in Greenland, while the other, *Libocedrus Sabiniana*, is referred to a species already described by Heer from twig impressions.

By far the most valuable part of this paper is the elaborate discussion entered into in seeking a name for the *Libocedrus*. He examined critically many living conifers to ascertain, if possible, whether the characters considered of most importance in describing fossil forms had any value in distinguishing living genera or species. The result was in the main negative for single or special characters, such as thickening of the cell walls, pits, or markings on the medullary rays, etc., but a combination of all possible characters was found to be of diagnostic worth. Thus the number and the size of the cells in the medullary rays he considers unreliable, but the relative volume of the ray cells as compared with the wood cells, among which they are placed, he considers of the highest value.

He also gives four elaborate tables, in which are presented systematized accounts of a microscopical examination of all recent and fossil species belonging to the groups *Araucarioxylon* and *Cupressinoxylon*. These tables, which are invaluable to the general student, represent hundreds of careful observations.

Felix also published an excellent paper in 1884, "Die Holzopale Ungarns in palaeontologischer Hinsicht,"² in which he established the new dicotyledonous genera *Alnoxylon*, *Liquidambaroxylon*, and *Staubia*, and described many new species belonging to well known genera. The most important part is his admission of the incongruity of the use of the prefixes *rhizo*, *cormo*, and *clado* to indicate wood of different parts of the plant. It works, as he admits, the greatest confusion in nomenclature, and he wisely concludes to abandon it. In the description of species, if one is fortunate enough to obtain material from all parts of the plant, it is best indicated by simple headings "root wood," "stem wood," or "branch wood," as the case may be. We have not three distinct genera, but simply a very perfect representation of a species of one genus.

Another important work which appeared during this year was J.

¹Fritz Beust. Untersuchung über fossile Hölzer aus Grönland. Allgem. schweiz. Gesell., neue Denkschr., vol. xxix, 1884, pp. 1-43, mit. 4 Tabellen u. 6 Tafeln.

²Jahrb. d. k. ung. geol. Anstalt, vol. 7, 1884, pp. 1-43, plates I-IV.

Schmalhausen's paper on the Tertiary flora of the southwestern part of Russia.¹ The paper is divided into four parts, the first three of which are devoted to descriptions of leaves, fruits, etc. The fossil wood described in the fourth part is from the *Spondylus* (Eocene) zone of Russia.

In regard to naming fossil wood, Schmalhausen concludes that the generic as well as the specific names must be comprehensive and possibly include several forms that would be regarded as distinct if we were provided with all the essential parts. Following out this line of argument he refers nearly all his specimens to the genus *Cupressinoxylon*, which, according to Mercklin, Schroeter and others, he considers may probably represent the wood of *Sequoia*. The well known structural resemblances between the wood of living *Sequoias* and the wood of the fossil genus, together with the marked abundance of species of *Sequoia* during Tertiary times make this seem very probable.

Six species are then described, three of which are considered to be new to science (*Cupressinoxylon glyptostrobinum*, *C. Mercklini*, and *Pityoxylon microporosum*). Three finely executed plates illustrate the structure of the wood.

Other papers were published during 1884 by Vater,² Solms-Laubach,³ Hofmann,⁴ and others.

In 1885 Dr. Conwentz described a collection of wood from the Rio Negro, in Patagonia,⁵ which possesses features of interest. The species are mostly coniferous and are all new to science. They are distributed as follows: *Cupressinoxylon*, four species; *Araucarioxylon*, one species and *Glyptostroboxylon*, the latter a new genus. The single angiosperm is called *Betuloxylon*, under which it is proposed to include the genus *Betulinium* of Unger. A list of all the known species is given.

Renault contributed, also in 1885, a valuable paper on the structure and position of the genus *Astromyelon*.⁶ It is illustrated by several fine plates.

In 1886 Dr. Felix published a continuation of his "Untersuchungen,"⁷

¹ J. Schmalhausen. Beiträge zur Tertiärfloora Südwest-Russlands. Paläontologische Abhandl. von Dames u. Kayser, vol. 1, Berlin, 1884, pp. 225-336, plates XXVIII-XLI.

² H. Vater. Die fossilen Hölzer der Phosphoritenlager des Herzogthums Braunschweig. Deutsch. geol. Gesell., Zeitschr., vol. 36, 1884, pp. 783-857.

³ H. Graf zu Solms-Laubach. Die Coniferenformen des deutschen Kupferschiefers und Zechsteins. Paläontologische Abhandl. von Dames u. Kayser, vol. 2, Berlin, 1884, pp. 81-116, plates XII-XIV.

⁴ Hermann L. Hofmann. Untersuchungen über fossile Hölzer. Inaug.-Diss. an d. Univ. Leipzig. Halle a S., 1884, pp. 1-44.

⁵ Dr. H. Conwentz. Sobre algunos árboles fósiles del Rio Negro. Academia Nacional de Ciencias en Córdoba (República Argentina), Boletín, vol. 7, Buenos Aires, 1885, pp. 435-456.

⁶ B. Renault. Recherches sur les végétaux fossiles du genre *Astromyelon*. Annales des Sciences Géologiques, vol. 16, 1885, pp. 1-34, pl. 7-9.

⁷ Dr. J. Felix. Untersuchungen über fossile Hölzer. Zweites Stück. Dent. geol. Gesell., Zeitschr., vol. 38, 1886, pp. 483-492, plate XII.

in which he describes six species, distributed as follows: *Pityoxylon inaequale*, from Alaska; *Pityoxylon Krausei*, from the Little Missouri, in Dakota; *Cupressoxylon erraticum*, Mercklin, from Copper Island, in Behring Strait; *Cupressoxylon*, cf. *sylvestre*, Mercklin, from Little Missouri, Dakota; *Laurinium Meyeri*, from New Guinea, and *Tænioxylon eperuoides*, from Negro Island, in the Philippines.

In a short paper¹ read before the American Association at the Buffalo meeting (August, 1886), Prof. E. W. Claypole reports the occurrence of *Dadoxylon antiquius* and *D. Newberryi* in the Carboniferous of Ohio. Other wood was found, but so poorly preserved as to be useless for purposes of determination.

Papers which were of less value were published by Blanckenhorn,² Beck,³ and others.

To treat in anything like an exhaustive or satisfactory manner the elaborate memoir of Professor Williamson on the organization of the fossil plants of the coal measures, of which mention was made above, would require much more space than is at my disposal, and an analysis of the contents and value of one of them must be taken as a sample of all. These papers have appeared from time to time, since 1871, in the Philosophical Transactions of the Royal Society of London. The first is on the Calamites, a group of Carboniferous plants that has been in confusion from time immemorial. In the beginning Professor Williamson propounds four questions concerning this group, as follows:

1. Do all the well known plants hitherto designated Calamites belong to one natural family, or there are two groups of these objects—the one cryptogamic, represented by the true *Calamites*, and the other phanerogamic, and represented by the *Calamodendron* of Brongniart?
2. Are there several genera, divisible into numerous species, with well marked internal characteristics, or are there but few specific types, each of which, though they are all constructed upon one common plan, exhibits a wide range of variability in the details of its internal organization.
3. What are the casts commonly known as Calamites, and what parts of the plants do their varied superficial markings represent?
4. To what living plants are these fossil forms most closely related?

To all these questions the specimens in hand suffice to give answers, according to Williamson, who, after describing minutely the structure of his specimens, proceeds to draw the conclusions from them.

To the first question he replies that the Calamites are undoubtedly cryptogamic, but that they possess a much higher organization than is seen in any of the living cryptogams, and there is proof that they have an undoubted exogenous mode of growth.

¹E. W. Claypole. Preliminary note on some fossil wood from the Carboniferous of Ohio. Am. Assoc. Adv. Sc., Proc., vol. 35, 1886, pp. 219-220

²Dr. Max Blanckenhorn. Die fossile Flora des Buntsandsteins und des Muschelkalkes der Umgegend von Commern. Palaeontographica, vol. 32, 1886, pp. 117-154, plates XV-XXI.

³Richard Beck. Beiträge zur Kenntniss der Flora des sächsischen Oligocäns. Deut. geol. Gesell., Zeitschr., vol. 38, 1886, pp. 342-352, plate VII.

To the second question he replies that we have two very distinct types of calamites clearly distinguished from one another by presence or absence of certain structural peculiarities.

The casts called Calamites he regards not as the result of filling up of cavities formed by decay, but by filling of cavities formed naturally by a process of absorption during the life of the plant.

That the modern Equisetaceæ are the only living representatives with which the Calamites can be compared he does not doubt.

Many elegant illustrations accompany the article.

In a similarly exhaustive manner are taken up the Lepidoendra, Sigillaria, Asterophyllites, etc.

GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF THE POTOMAC FORMATION.

It is now necessary to discuss briefly the geological position and geographical distribution of the formation from which the wood herein described was obtained. This formation was described at length by Prof. W. B. Rogers in the annual report of the geological survey of Virginia for 1840,¹ where it was designated as the *Jurasso-Cretaceous* or Upper Secondary Sandstone. It is laid down upon the primary rocks along their eastern boundary in the State of Virginia and is in its turn overspread by undoubted Tertiary strata. The Potomac formation, the name by which it is now more generally known, is the one proposed by the U. S. Geological Survey to distinguish it as a local formation and to fix more definitely its position in the geological scale. From the palæobotanical evidence available in 1885 Mr. W. J. McGee considered it to be "Lower Cretaceous in age—the American equivalent of the European Neocomian."² Prof. William M. Fontaine, on the other hand, from an exhaustive study of the leaf and cone impressions, is inclined to regard it as belonging to the Wealden, while Prof. O. O. Marsh, who has studied the animal remains, regards it as Jurassic.

As to the nature of the material comprising this formation Rogers says:³ "These strata consist of sandstones, slates, shales, and conglomerates, and, as might be anticipated, display much variety as to color, texture, and solidity." In and about the District of Columbia, Mr. McGee describes it as being composed of "mottled clays, gravels, and laminated sands and clays." It is thus observed to present considerable diversity of character and, as might be expected, offers in the different members very unequal conditions for preservation of organic remains. It attains in some instances, as along Potomac Creek, an observed thickness of from sixty to seventy feet, but in general the expos-

¹ See *Geology of the Virginias*, pp. 437-449. New York, 1884.

² *The Geology of the District*. The Evening Star, Washington, July 11, 1885.

³ *Op. cit.*, p. 442.

ures are much less than this, being rarely over thirty or forty feet. Its total thickness must be two hundred or three hundred feet, or even more.

The geographical distribution, both on the north and on the south, has been extended considerably beyond the points indicated by Professor Rogers. Thus the southernmost point at which the Potomac formation has been detected is Weldon, North Carolina, where it was observed by Messrs. McGee, Fontaine, and Ward, in July, 1885. From this point it extends almost directly north, occurring in irregular and scattered outcrops, to the Nottoway River, which was indicated as the southern limit by Rogers. From Petersburg it extends northward in a narrow belt, offering good exposures on the Appomattox, James, South Anna, North Anna, Rappahannock, and Potomac Rivers. It touches the Potomac at Acquia Creek, and, extending up past Mount Vernon, which Rogers considered as the northern terminus, embraces a large portion of the District of Columbia. Thence it extends to Baltimore, where extensive outcrops containing abundant plant remains have been observed by Mr. McGee. The most northern point at which this formation has been identified by fossils is near Havre de Grace, at the head of Chesapeake Bay. This outcrop was visited by Messrs. McGee and Ward in 1885, and a few plant remains were obtained, but a more extended exploration is necessary to complete our knowledge of this locality. Quite recently gravelly deposits, evidently representing this formation, have been observed by McGee on the highlands of northeastern Maryland, northern Delaware, and southeastern Pennsylvania, overlooking Chesapeake and Delaware Bays, as far north as the Schuylkill River. It may yet be found that the Raritan clays of New Jersey rest conformably upon the Potomac formation, but of the truth of this we can only conjecture at present.

THE ORGANIC REMAINS AND THEIR MODE OF OCCURRENCE.

The organic remains of the Potomac formation occur principally in lenticular pockets of a hard, bluish clay, which bear evidence of having been transported in mass from the original bed in which they were laid down. These pockets vary in their dimensions, some being only a few feet in length and one or two feet in thickness, while others are two or three rods long and from three to ten feet thick. It is more than probable that originally this material was deposited in shallow water, which was fresh, or at most but slightly brackish. An unknown thickness, filled with the débris of vegetable growth, was here accumulated, after which there was a gradual uplifting of the land. This newly emerged land was now subjected to the powerful action of moving water, which cut down and transported a large portion of it, leaving now and then these irregular or lenticular masses, which were eventually surrounded and covered by a lighter material, and the whole was finally buried under the Tertiary.

Good exposures of this formation, containing lignite and silicified wood, occur at Fort Washington, White House Landing, and Acquia Creek on the Potomac; at Dutch Gap and vicinity, on the James River; and also in the cities of Washington and Baltimore, where excavations have been made. Cuts along the lines of railways which pass through this formation often give good sections. Most of the specimens described in the following pages came from these localities.

The wood of this formation occurs under two widely different conditions, viz: as lignite and as silicified wood. There seems to be almost no transition between the two forms, although in one instance, in a silicified specimen from the new reservoir, Washington, a few small lignitized areas were detected. There is reason for supposing, however, that some of the silicified forms are also represented in a lignitized state, that is, owing to different conditions of fossilization some specimens of a species were silicified, while others were turned to lignite.

The lignite is much more abundant than the silicified form, occurring in the above mentioned lenticular masses in pieces of considerable size and in the loose surrounding material as minute fragments, which shows that this latter is the result of the wearing away of a large part of the original deposit. One of the largest specimens noted was found at Fort Washington. This was a log about five feet in length, eight inches in width, and four in thickness. A cross-section of this specimen of course would have been lenticular, showing that it had been subjected to great pressure. A transverse section, as seen under the microscope, (Pl. I, Fig. 2), shows the cells completely collapsed and distorted by the pressure.

In color this lignite is almost uniformly jet black, in a few cases being of a slightly brownish cast. It has a specific gravity of about 1.333.¹ and breaks with a true conchoidal fracture like ordinary anthracite. When thus broken it does not exhibit superficially the slightest trace of organic structure (see Pl. I, Fig. 5 c), although careful microscopic examination of thin sections shows it to be generally present. It may, however, be split along certain lines, notably in a direction parallel to the medullary rays, where very plain structure shows superficially. Viewed as an opaque object (Pl. I, Fig. 5), the outlines only of the wood cells and medullary rays are detected.

Supposing a priori that all parts of this lignite must exhibit traces, at least, of organization, its intense blackness naturally becomes a serious obstacle in the way of a satisfactory examination, since, in order to make a successful study with the higher powers of the microscope the specimen must be thin enough to be viewed by transmitted light. An attempt was made to grind down sections, after the usual manner of cutting rock sections; but, even when the sections were so thin as to begin to break in fragments and be torn from the slide, they still remained too opaque for even a ray of light to pass through. Other

¹ Kindly determined for me by Mr. George P. Merrill, of the U. S. National Museum.

ethods, as incineration, boiling in acids, etc., were equally unsuccessful. The method finally adopted, and which proved eminently successful, was that recommended by Griffith and Henfrey in their *Micrographic Dictionary*, second edition (p. 178), for the examination of coal. The specimens are macerated for a week or more in a strong solution of carbonate of potash, "at the end of which time it is possible to cut tolerably thin slices with a razor. These slices are then placed in a watch glass with strong nitric acid, covered, and gently heated; they soon turn brownish, then yellow, when the process must be arrested by dropping the whole into cold water, or else the specimen would be dissolved. The slices thus treated appear of a darkish amber color, very transparent, and exhibit the structure, where existing, most clearly." The specimens are then carefully washed in pure water and are best examined in glycerine, and may be mounted permanently in cells of this fluid.

The translucency obtained by this process is brought about by the dissolving out of the hydrocarbons by the potash. This shows that there can be little or no free carbon present, else it could not be dissolved by the liquids used. The intense yellow color produced is probably due to the presence of picric acid, of which, owing to its great coloring power, only a trace would be necessary.

The silicified wood occurs in situations similar to the lignite, but generally in larger pieces. One trunk seen by Messrs. McGee and Ward at the new reservoir, Washington, was about twenty feet below the surface and was reported to have been between thirty and forty feet long. It had a diameter of nearly two feet and was but slightly flattened. Other smaller specimens from the same locality were more flattened, and a transverse section as seen under the microscope shows the cells to be distorted by pressure. Generally, however, the tissue is very perfectly preserved in the silicified specimens and admits of careful dissection and study.

In color the specimens vary from almost white to jet black, sometimes showing a transition between the two colors in the same specimen. The only examples of a decided yellow were collected by W. J. McGee in a cut on the Baltimore and Ohio Railroad half way between Montello and Rives Station, D. C. These were small fragments; yet they have the structure very perfectly preserved in places.

The method employed in preparing these woods for study is that commonly followed in the preparation of petrographic specimens, viz: slicing and grinding to the requisite thinness and mounting in Canada balsam.

SYSTEMATIC DESCRIPTION OF LIGNITE.

A great many specimens of lignite have been examined by the process mentioned above—from Baltimore, from the new reservoir and vicinity, Washington, from Fort Washington on the Potomac, from the Dutch Gap on the James River, and from other localities throughout the area covered by this formation—and the result, although not as sat-

satisfactory as could be wished, is probably all that could be expected under the circumstances. The most casual examination shows that the material has been subjected to great pressure, which has so entirely crushed and distorted the cellular elements that it is difficult in many cases to recognize the original form. The examination of a large series of sections serves, however, to give a pretty correct general idea of

A transverse section like that given in Plate I, Fig. 2, shows the lumen of the cells to be almost entirely closed up by lateral pressure. This specimen, which was collected in the new reservoir, Washington, by Mr. McGee, is one of the best obtained. In most of those studied the pressure had seemingly been greater, and consequently the original outlines of the cells were more difficult of determination, as they had been crushed and crowded upon one another in great confusion.

A radial section shows the medullary rays to be in great abundance (Plate I, Fig. 3), and, like the wood cells, to have been considerably distorted by pressure. In a few cases some of the cells of the rays were still before being subjected to this pressure, with a hard substance, which was more resistant to pressure, and consequently they retain nearly their original form. The infiltration of this substance must have been quite accidental and without any regularity of action, since not one cell in twenty is thus preserved. The irregular distribution of these rays is shown by a glance at the tangential section (Plate I, Fig. 1). The number of cells entering into the composition of each ray varies considerably, ranging in vertical section from as few as two or three to as many as fifty or more. By this is to be understood the average of all the specimens examined. In some of the specimens, as for example those from the new reservoir, the rays are rarely ever more than twenty cells high, while in others there may be as many as forty or fifty. In most cases the rays are but one cell broad, although in a few instances sections have been obtained with the rays two cells broad. In one poorly preserved example there seemed to be several cells, perhaps as many as four, with a larger one in the center. This appearance may have been the result of pressure, and, if so, would of course have no value, but if natural it would indicate that the specimen belonged to the genus *Pityoxylon*. It was, however, too indefinite to be more than suggestive.

As for pits or markings on the rays, they seem to have been pretty generally wanting, or, at most, rarely to have been preserved in a satisfactory manner. They have been observed only in one instance (Plate I, Fig. 3 b), where only two pits or circular markings were noted. In radial sections the cells that have been filled with the harder substance present a slightly different appearance, being granular. I at first took this granulation for evidence of markings on the walls, but a more careful study convinced me that it was due to the above cause.

In tangential sections the medullary rays are seen to be very numerous, but this appearance is due partly to the collapsing of the wood-cells by pressure, by which they are made to occupy nearly one-third of

space than when in a turgid condition, thus bringing a greater number of rays into the field at once. Most of the cells are crushed flat, only those above mentioned escaping.

In regard to the identification of this lignite it is manifestly impossible to attempt more than an indication of its general character and position. That it is coniferous is beyond question. The absence of wood elements other than tracheids, which were provided in some cases at least with bordered pits, and the number and arrangement of medullary rays, make the coniferous nature clear. From the abundance of the genus *Cupressinoxylon* in the Potomac Formation, as shown by the silicified examples, it is probable that most of the lignite may be also of this genus, particularly as there is in many cases a marked resemblance, so far as I am able to interpret the distorted structure, between it and some of the species described from silicified specimens. This is, however, little more than conjecture.

The variation in height and in breadth of the medullary rays, as described above, indicates that several species, as species of fossil wood are understood, entered into the formation of this lignite. Whether these characters are of sufficient importance to merit specific distinction is a question still undecided.

SYSTEMATIC DESCRIPTION OF SILICIFIED SPECIES.

CUPRESSINOXYLON Göppert.

*Cupressinoxylon*¹ Göppert, Mon. foss. Conif., 1850, p. 196.

This genus, as it is now emended, is a somewhat comprehensive one, including, according to Kraus, what were regarded at one time as several distinct genera. Thus we have *Thuioxylon* of Unger and Endlicher, *Physematopitys* of Göppert, a part of *Pinites* of Göppert, and *Peuce* of Witham, all embraced under *Cupressinoxylon*. This modern extension of the generic characters in the study of fossil wood is the direct result of our more extensive and exact knowledge respecting the internal structure of living forms, for in this department, as in all the departments of paleontology, our knowledge of the fossil types is derived almost entirely from comparison with their most nearly related living representatives. As our knowledge of the internal organization of living conifers has been gradually worked out by Göppert, Kraus, Beust, and others, the fact has become more and more apparent that types founded upon these characters alone must be regarded in a measure as comprehensive; that is, species founded upon external characters may so much resemble one another in internal structure that it will be impossible to distinguish them; and in like manner what are regarded as genera may resemble one another to such an extent that, if we had

¹ There is a considerable diversity among authors as to the way this word is to be spelled, but I prefer to follow Göppert, not only because his name has the claim of priority, but because it is etymologically correct. The root is from the tribal name *Cupressinæ*, and not simply the generic word *Cupressus*.

them only in a fossil state, we should be obliged to refer them to a single type. We are able in all cases, however, to recognize families and tribes, and, as the above example is an extreme case, we are able to distinguish genera in many instances.

This looseness, or expansiveness, of structural characters does not by any means invalidate the results obtained from their study, for, as Williamson truly says, nothing can have the value that a study of internal organization has; "it is the basis upon which all recent botany should rest," and through it and by it must we seek for the explanation of many of the otherwise inexplicable problems of the origin of various types of vegetation and of the line of development that has been followed by them. If it can be shown that a number of species or genera have an identical or but slightly dissimilar cellular structure, then we have an argument that can not be controverted of their community of origin, for the characters drawn from leaves, flowers, or fruits, upon which recent species are founded, are the most plastic and those most readily modified by change of environment. The structural elements, on the other hand, are more permanent, and undergo change and modification much more slowly. As proof of the value of this method may be cited the now very generally acknowledged systematic position of the Coniferae. Botanists have generally placed the Coniferae between the monocotyledons and dicotyledons on account of their exogenous mode of growth, but paleobotanists have all along insisted that their true position was between the cryptogams and the phanerogams and have substantiated their arguments by showing that there is a gradual transition from some of the higher cryptogams, which are only known in a fossil state, to undoubted conifers. So indistinct is this line of demarcation that many eminent paleobotanists have placed the *Sigillaria* which are now believed to be true cryptogams, among the Coniferae.

The genus *Cupressinoxylon* is characterized by Kraus as follows:¹

Lignum stratis concentricis distinctis, angustis; cellulis prosenchymatosi porosis poris magnis, rotundis, uni vel pluriserialibus, oppositis; cellulis resiniferis crebris, ductibus resiniferis nullis; radiis medullaribus simplicibus.

The various specimens that I have examined from the Potomac Formation belong, with one exception, to this genus, which is the large one founded upon internal structure. Most of the specimens are rather small, although a few, as for example, those from the new reservoir at Washington, are from trunks that were of very large size. In the structural details these specimens exhibit affinities with some described species, but as they differ in one or more of the characters that are considered of importance I have described them all as new. The view of this specific distinctness is still further strengthened by the fact that the species most nearly related to them come from different horizons and also from distant localities. The question of relationship will be discussed under each species.

¹ In Schimper: *Traité, Pal. Vég.* Vol. II, p. 374.

CUPRESSINOXYLON PULCHELLUM, n. sp.

Plate II, Figs. 1-4.

tion.—Annual ring moderately distinct, 1.25 to 3^{mm} broad; small, rather thick walled, with bordered pits only on radial side in a single row; medullary rays numerous, simple, 1 to 15; resin ducts numerous, of a chain of short thin walled cells. The specimen upon which the above species is founded was collected by J. H. Sayles, of the U. S. Geological Survey, at Spring Hill, on the left bank of the Appomattox River, half way between Petersburg and City Point. It is a perfectly silicified fragment about 12^{cm} in length and 1.5^{cm} in diameter. In transverse section the pith is very clearly observable, lying a little to one side of the exact center of the specimen. Medullary rays show very distinctly even to the naked eye. The annual rings are much less distinct than the rays, but may be observed with a little aid of hand-glass. The general color of the specimen is yellowish-brown, mottled in places by patches of black, due to the infiltration of

Microscopic analysis.—Transverse section: As above stated, the wood is well preserved and is found to consist, when viewed under a microscope, of numerous large, rather thick walled cells, with an almost nearly circular outline. The larger cells, which have a diameter of from .05^{mm} to .08^{mm}, occupy the center, from which they decrease in size and pass more or less gradually into the medullary rays. The rays are very numerous and pass in nearly a straight line to the outer edge. Unfortunately no trace of the bark remains. The cells are arranged with great regularity in radial rows, and are of nearly equal size for their small size, particularly where they are in contact with each other. As the medullary rays diverge, new layers of tracheids are added to fill up the space, as shown in Plate II, Fig. 2. The distinction between the annual layers is generally well defined, the late wood (Herbstholz of the Germans) consisting of from five to seven layers of small, thin walled cells in each radial row. The spring wood (Frühlingsholz) consists of much larger cells, which have a diameter of from .035^{mm} to .05^{mm}. These cells are more nearly hexagonal than the others, and as they increase gradually in size, pass into the next ring of fall wood. Longitudinal section: In this section the tracheids are seen to be long and narrow, with a single longitudinal row of bordered pits, which have an outer diameter of from .017^{mm} to .021^{mm}. The inner circle of the tracheid is rather small, with a diameter of from .005^{mm} to .006^{mm}. The medullary rays are cut up into comparatively short cells, each one covering the space of five or six of the tracheids; markings seem to be present on the walls of the rays, but the real state of affairs may be obscured by the petrifying material, which has evidently somewhat destroyed the original structure. The resin ducts are numerous, as is shown by the presence of two in the section figured. (Pl. II, Fig. 1).

These ducts (Harzzellen of the Germans; conduits résineux simples of the French) consist of a chain of short, regular cells, which are slightly constricted at the ends. The individual cells are from .08^{mm} to .15^{mm} in length, and are usually filled with minute globules of darker matter, represented by dots in the drawing.

Tangential section: In this section the medullary rays are seen to be very abundant. They are always simple and consist of a single layer, which ranges from 1 to 15 cells in height, the average number being about seven or eight. The tracheids do not show bordered pits on the tangential walls, a fact of considerable importance.

There are points of resemblance between the Potomac form and the following described species: *Cupressinoxylon sylvestre* Mercklin (Palæodendrol. ross. p. 58, pl. xiii, figs. 1-6), *Cupressinoxylon Breverni* Mercklin (op. cit., p. 71), *Cupressinoxylon pachyderma* Göppert (Mon. foss. Conif., p. 199, pl. xxv, figs. 1-2), *Cupressinoxylon juniperinum* Göppert, *Thuoxylum juniperinum* Nug. (Chlor. prot., p. 31), and *Oladocupressinoxylon Protolarix* Felix (Stud. ü. foss. Hölz., p. 46). These species all differ, however, in one or more characters, which are considered of taxonomic value, from the Potomac species, which I have consequently ventured to describe as new. More complete and perfect material may show the relationships to be closer than is now suspected; but even in that case it would be doubtful whether the species were identical, coming as they do from such widely different geological and geographical positions.

CUPRESSINOXYLON MCGEEI, n. sp.

Plate II, Fig. 5; Plate III, Figs. 1-5.

Description.—Annual ring very distinct, from 2^{mm} to 4.5^{mm} broad; tracheids remarkably large, thick walled, closely covered with from one to three rows of large bordered pits on the radial walls and a few scattered ones on the tangential walls; medullary rays simple, from 2 to 49 cells high, covered on the lateral walls with numerous oblong pores; resin ducts simple, numerous, composed of a chain of thin walled cells.

The type of this species was collected by W. J. McGee, of the U. S. Geological Survey, from excavations made for the new reservoir of the water-works extension, Washington, D. C. It had originally a length of nearly forty feet and a diameter of almost two feet. It was somewhat flattened by pressure, the shorter diameter being considerably less than the longer. The trunk was exposed at a depth of about twenty feet below the surface, and must have belonged originally to a tree of large size. To the naked eye the annual rings are very indistinct. The medullary rays, however, are easily observed and are seen to pursue a very tortuous course, due, in part at least, to the dislocation caused by the pressure to which it had been subjected. The bark was not preserved in any of the pieces examined.

Microscopic analysis.—Transverse section: This section shows the

tracheids to be arranged in strict radial rows, and also indicates their real size. The annual ring, as above stated, is broad, consisting in some cases of as many as fifty or sixty of the larger and from ten to sixteen of the smaller thick-walled cells. The larger cells are mostly quadrangular in outline and have a diameter in some instances of $.080\text{mm}$, the average being about $.068\text{mm}$. The cells of the fall wood have very thick walls and are much flattened. Intercellular spaces are frequently observed, particularly where additional rows of tracheids have been intercalated (Pl. III, Fig. 1. c). The medullary rays are moderately numerous.

Radial section: The large size of the tracheids is very clearly shown in this section, most of which is made up of summer wood. The tracheids in the fall wood are, of course, much smaller and are covered with but a single row of pits. The bordered pits are very close together on the summer wood and are always in two and in some exceptionally large cells in three rows. They are also very large, the outer circle having a diameter of from $.020\text{mm}$ to $.025\text{mm}$, and the inner of from $.005\text{mm}$ to $.008\text{mm}$. The walls of the medullary rays are marked by large oval pores, from one to three of which occupy the width of a single wood cell. These pores are about $.015\text{mm}$ in length and $.010\text{mm}$ in the short diameter. The resin ducts consist of a chain of short, small, thin-walled cells, which now contain a small quantity of granular matter, representing probably the drops of resin. The individual cells have a length of from $.12\text{mm}$ to $.25\text{mm}$ and a diameter of about $.05\text{mm}$, slightly less, it will be observed, than the tracheids among which they run.

Tangential section: The medullary rays are always simple; that is, they consist of but a single row of cells, which varies from 2 to 49 cells in height. The tracheids are provided on the tangential walls with a few scattered bordered pits. These have a diameter of from $.016\text{mm}$ to $.021\text{mm}$.

This species, which I take pleasure in naming in honor of the collector, shows remarkable affinities with several species that have been described by Mercklin from the Tertiary of Russia. So close, indeed, is the resemblance that I was at first inclined to describe it under one of Mercklin's names, but a more careful examination has shown points of difference which seem to entitle it to specific rank. Thus *C. equoianum* Mercklin, which has been reduced to a synonym of *C. panonicum* by Felix (Die Holzopale Ungarns, 1884, p. 36), differs in size of the tracheids and in the size and shape of the pits on the radial walls. The ray cells are also unlike in shape, and they differ in the number of cells that compose them. In *C. erraticum* and its variety *Teredinum* of Mercklin (Palæodendrol. ross., pp. 60-63, pl. xiv and xv) the individual resin cells are much larger and not at all constricted at the ends. The tracheids are smaller and mostly provided with one and more than two rows of bordered pits. The pits on the walls of the

medullary rays also differ in size and shape. There are also points of resemblance with *C. nodosum* Göppert (Mon. foss. Conif., p. 203, pl. xxviii, figs. 1-4) and *Peuce* (*Cupressinoxylon?*) *affinis* Unger (Chlor. prot., p. 36), but they are more remote and hardly worth consideration. Besides these variations in anatomic features there still remains the greater one of the difference in geologic horizon. *C. McGeei* comes from the Jurassic or the very lowest Cretaceous, while all of the above species are found in the Tertiary, and Kraus has given as his opinion that species can be very rarely traced from one formation to another without changes in form.¹

CUPRESSINOXYLON WARDI, n. sp.

Pl. IV, Figs. 1-4: Pl. V, Figs. 1, 2.

Description.—Annual ring distinct, moderately broad; tracheids medium in size, the radial walls bearing one, rarely two, rows of bordered pits; medullary rays two cells broad and from one to thirty-five cells high; resin ducts simple, not numerous.

This species is represented by specimens from the localities which have been designated by the letters A and B, respectively.

A. Several small fragments collected by W. J. McGee in a cut on the Washington Branch of the Baltimore and Ohio Railroad about half way between Montello and Rives Station, D. C. The largest piece is only 8^{cm} long, 6^{cm} wide, and 1^{cm} thick, and the others are much smaller. They are all very poorly preserved, and the structure can be made out only in a few favored spots.

B. A small piece, hardly 5^{cm} square, collected by Lester F. Ward from Freestone Cut, on the Neabsco Creek, Virginia. Like the other specimens, this is very badly preserved, and the structure has entirely disappeared in many places.

The specimens from both localities are yellow in color, and have the cavities in them filled with minute quartz crystals.

Microscopic analysis.—Transverse section: The fragments are all too small and too poorly preserved to show the annual rings to the naked eye, but under the microscope they are observed to be tolerably distinct. The ring of fall wood consists of from three to six or eight compressed cells in each radial row. The spring wood contains some very large cells, with a diameter in some instances of .062^{mm}. The number of cells in each row of tracheids varies according to the width of the annual ring, there being frequently as many as one hundred. Large intercellular spaces occur particularly where additional rows of tracheids have been introduced.

Radial section: In this section the tracheids are shown to be provided with one row, or, in some rare instances, with two longitudinal rows of bordered pits. They occupy the center of the cell and are close together, almost touching in some cases. The larger have a diameter

¹ Kraus in *Traité Pal. Vég.*, W. P. Schimper, Vol. 2, p. 368.

20^{mm}, and the smaller a diameter of .015^{mm}. The medullary rays consist of typical parenchymatous tissue. The individual cells are thick, covering the width of from four to eight tracheids. I have not been able to detect markings on the walls of the rays, but this may be accounted for by the poor state of preservation of the specimens. The resin ducts are not numerous. They are of nearly the same size and shape as the tracheids, and in fact look very much like tracheids with transverse partitions. They are almost always empty.

Longitudinal section: The tracheids are not provided with pits on the radial walls, or at least none have been detected. The medullary rays in many cases are two cells broad, and, as above indicated, from ten to thirty-five cells high. The individual cells of the rays have a diameter of from .017^{mm} to .030^{mm}.

This species I take pleasure in naming in honor of Prof. Lester Ward, who collected the specimen from Neabsco Creek. It has, like the others, affinities with several described species, but the resemblances are too vague to suggest specific identity.

CUPRESSINOXYLON COLUMBIANUM, n. sp.

Pl. IV, Fig. 5; Pl. V, Figs. 3, 4; Pl. VI, Figs. 1-5; Pl. VII, Fig. 1.

Description.—Annual ring very broad, indistinct; tracheids very thick walled, provided with one or two rows of small pits; medullary rays consisting of one layer of small, thick walled cells, ranging from five to forty cells in height; resin ducts numerous, of a chain of short thick walled cells.

This species is also represented by specimens from two localities.

A piece 15^{cm} long, 10^{cm} wide, and 5^{cm} thick, collected by W. J. Peck at the Dutch Gap Canal on the James River, about twenty miles from Richmond, Va.

Several larger pieces, some of them 25^{cm} long, collected by Prof. William M. Fontaine, of the University of Virginia, from "sandy clay, one mile north of Mr. Kankey's house, near Neabsco Creek, Virginia." These specimens from both localities have been severely crushed by pressure, and in places are much distorted. They are grayish in color, and marked in places by streaks of black.

Microscopic analysis.—Transverse section: The annual ring is very distinct, although not entirely absent, as I have observed slight traces of it among a mass of crushed cells. The tracheids are arranged in regular radial rows, and are remarkable for their nearly uniform size and thick walls. The larger cells are about .050^{mm} in diameter, the smaller from .030^{mm} to .040^{mm} in diameter. The medullary rays are abundant and appear very narrow as seen in this section.

Radial section: The tracheids are here seen to be thick walled and are covered with one or rarely two rows of bordered pits, which are very small. The larger pits have a diameter of .015^{mm} and the smaller

a diameter of only .010^{mm}. The rays consist of long cells, in some cases provided with minute round punctations. Thus the specimen from Dutch Gap exhibits them in places, but the Neabeco Creek specimens show but slight traces of them. The resin ducts are numerous, two of them appearing side by side in a single figure (PL VI, Fig. 2). In most cases they consist of a regular chain of short cells constricted at the joints. The cells of the specimen from Dutch Gap are filled with a multitude of minute round globules. In the other specimen they are nearly empty.

Tangential section: The medullary rays are shown to have very small cells which have a long diameter of from .015^{mm} to .017^{mm} and a short diameter of only .010^{mm}; the walls of the tracheids are so thick and the rays so small that the walls between which they appear are but slightly "bulged." The tracheids do not exhibit pits on the tangential walls.

There are resemblances between this species and several other described species, but they are not of sufficient importance to require extended consideration, particularly as they occur in widely separated geologic and geographic positions.

ARAUCARIOXYLON Kraus.

Araucarioxylon Kraus, 1870-72. In *Traité Pal. Vég.*, W. P. Schimper, vol. 2, p. 380.

Araucarites Presl., 1820-38. In *Sternberg's Vers.*, vol. 2, p. 203.

Pinites Witham, 1833. *Int. Struct., Foss. Veg.*, etc., p. 72.

Dadoxylon Endlicher, 1847. *Synop. Conif.*, p. 298.

Pissadendron Endlicher, 1842. *Gen. Plant. Suppl.*, vol. 2, p. 27.

Palæoxylon Brongniart, 1849. *Tableau des genres de végétaux fossiles*, p. 77.

ARAUCARIOXYLON VIRGINIANUM n. sp.

Plate VII, Figs. 2-5.

Description.—Annual ring very indistinct, about 2^{mm} broad; tracheids bearing one or two rows of hexagonal pits on the radial walls; medullary rays simple, of from 1 to 27 superimposed cells; resin ducts none.

This species, the only one of the genus that has been found in the Potomac formation, was collected by W. J. McGee, at Taylorsville, Va. It is a small piece, only about 10^{cm} long and 6^{cm} square, and is grayish in color. The structure is very well preserved, although somewhat disorganized in places by the process of silicification.

Microscopic analysis.—Transverse section: The annual ring is not perceptible to the naked eye, but when a thin section is examined under the microscope it is observed to be present. The actual ring or line of demarkation between the layers consists of only three or four rows of slightly smaller and thicker walled cells. In the living species of *Araucaria* the annual ring is usually indistinct and not infrequently entirely absent, both conditions sometimes obtaining in different parts of the same plant.

The tracheids are prominent and have rather thick walls. The indi-

lual cells have a diameter in some instances of $.051^{\text{mm}}$, the average being perhaps $.0375^{\text{mm}}$. They are arranged in radial rows, which are not pronounced in proximity to the medullary rays. In places when additional layers of cells have been intercalated, considerable intercellular spaces have been left that are now filled with nearly transparent silica.

Radial section: The radial walls are the only ones observed to bear ordered pits. The number of rows vary, even on the same cell, from one to two. When there is but one row they occupy the center of the cell and are in contact. They are then nearly circular in outline, and have a diameter of from $.017^{\text{mm}}$ to $.020^{\text{mm}}$. When there are two rows they are in contact and alternate with each other, and have a nearly regular hexagonal outline. These hexagonal pits have a diameter of from $.016^{\text{mm}}$ to $.021^{\text{mm}}$. The inner pore is very small, being only about $.0025^{\text{mm}}$ to $.0030^{\text{mm}}$ in diameter.

Tangential section: The rays as seen in transverse section are shown to be single and to range from one to twenty-seven cells in height, the average number being about ten or twelve.

There have been thus far about forty species characterized from the wood which are now referred to the genus *Araucarioxylon*. This genus, as now emended, is of very great antiquity, having had its origin in the Middle Devonian, from which Dawson has described five species in this country, and has continued uninterruptedly to the Lower Miocene, from which several species are known. The living species, which show remarkable affinities with some of the fossil forms, are undoubtedly the lineal descendants of the ancient line. The antiquity is further confirmed by the number of species that have been described from leaf or cone impressions. According to Zincken, thirty-eight species have been reported from below the Carboniferous, forty-two from the Carboniferous proper, ten from the Triassic, eighteen from the Jurassic, ten from the Cretaceous, and one from the Tertiary. Some of these latter species may represent the branches or cones of some of the forms described from the wood alone, but we are at present unable to correlate them, and probably shall always remain so. It would be very satisfactory if we could correlate many of these supposed identical forms, for by so doing the number of paleontologic criteria would be reduced, and their value as stratigraphic marks proportionately enhanced. However, we must take them as they are and look to more careful research in the future to supply, if possible, the links.

In indicating that the above species is new to science I have followed the method of exclusion adopted by Beust in his admirable paper on the Fossil wood of Greenland.

Taking the markings on the wood cells and the height and the breadth of the medullary rays as the most important diagnostic characters, an examination of the described species gives the following results:

Species which have but one longitudinal row of bordered pits:

<i>Araucarites Edvardianus</i> Göpp.	<i>Araucarites orientalis</i> Göpp.
<i>Araucarites Keuperianus</i> Göpp.	<i>Araucarites biarmicus</i> Kut.
<i>Araucarites stellaris</i> Göpp.	<i>Araucarioxylon Schmidianum</i> Fel.
<i>Araucarites Schrollianus</i> Göpp.	<i>Dadoxylon subrhodæanum</i> Grand'Eury.

Species bearing from two to three rows:

<i>Araucarites Rollei</i> Göpp.	<i>Araucarites carbonaceus</i> Göpp.
<i>Araucarites Valdejoensis</i> Mougeot.	<i>Araucarites argillicola</i> Eichw.
<i>Araucarites subtilis</i> Mercklin.	<i>Dadoxylon annulatum</i> Dawson.
<i>Araucarites materiarum</i> Göpp.	<i>Dadoxylon antiquius</i> Dawson.
<i>Araucarites Brandlingi</i> Göpp.	

Species having one to three or more rows:

<i>Araucarites Egyptiacus</i> Göpp.	<i>Araucarites ambiguus</i> Göpp.
<i>Araucarites Saxonicus</i> Göpp.	<i>Araucarites Richteri</i> Göpp.
<i>Araucarites medullaris</i> Göpp.	<i>Araucarites pachytichus</i> Göpp.
<i>Araucarites cupreus</i> Göpp.	<i>Araucarites Stigmolithos</i> Göpp.
<i>Araucarites permicus</i> Mercklin.	<i>Dadoxylon intermedium</i> Grand'Eury.
<i>Araucarites Beinertianus</i> Göpp.	<i>Pitys</i> With. et Lindl.
<i>Araucarites Tchihatcheffianus</i> Göpp.	
<i>Araucarites acadianus</i> Göpp. [<i>Dadoxylon</i> Dawson].	

It now remains to examine such as have from one to two rows of bordered pits, and to show the points of variation between them and the Potomac species:

Araucarites Kutorgæ Mercklin. From the Permian of Russia. The medullary rays consist of from 4 to 15 cells.

Araucarites vogesiacus Göpp. From the Lower Carboniferous of Niederburbach. Cells of the ray from 1 to 20.

Araucarites stephanense Grand'Eury. From the Carboniferous of France. This species has the rays only 1 to 3 cells high.

Araucarioxylon Heerii Beust. From the Lower Miocene of Greenland. Ray cells from 1 to 82 in number.

Araucarioxylon Rhodæanum Göpp. From the Permian of Silesia. The rays are composed of two rows of cells.

It will be observed from this list that the species with which our plant shows the greatest affinity are all from the Carboniferous or the Permian of Europe; but it would be unreasonable to suppose, provided the identity was close, that any of them had continued unchanged from the Carboniferous to the Potomac formation, for, as before stated, species rarely pass unchanged from one formation to another.

These considerations teach us that the species under discussion differs in essential points from any that have heretofore been described. I have named it *Araucarioxylon Virginianum*, from the State in which it was obtained.

PLATES.

PLATE I.

PLATE I.

FIGS. 1-5. Lignite.

FIG. 1. From the new reservoir, Washington.

Tangential section. *a, a, a*, cells of medullary rays filled with hard, black substance. $\times 67$.

FIG. 2. From the new reservoir, Washington.

Transverse section. *a*, distorted medullary ray. $\times 242$.

FIG. 3. From the new reservoir, Washington.

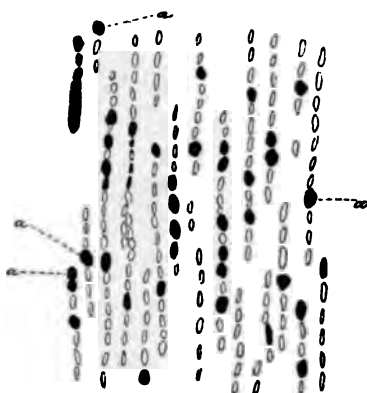
Radial section. *a*, bordered pit on well-preserved tracheid; *b*, two small pits on medullary ray. $\times 242$.

FIG. 4. Source unknown.

Tangential section, showing two badly crushed and distorted medullary rays.
 $\times 242$.

FIG. 5. From Neabsco Creek, Va.

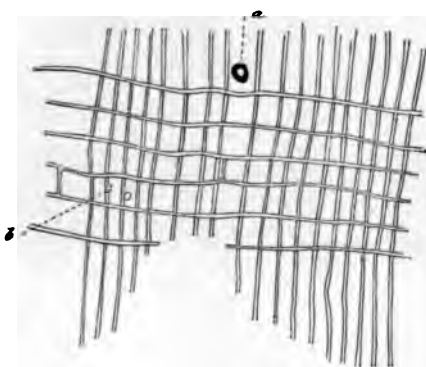
Natural size. *a*, annual rings; *b*, traces of medullary rays; *c*, surface exhibiting conchoidal fracture and no trace of structure.



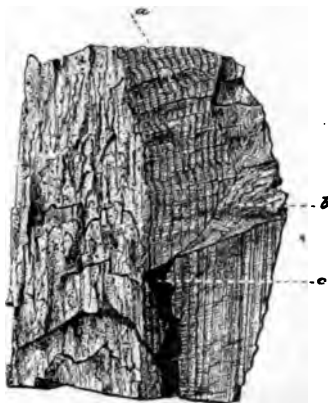
1.



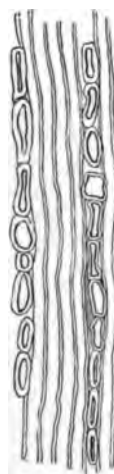
2.



3



5.



4.

PLATE II.

PLATE II.

FIGS. 1-4. *Cupressinoxylon pulchellum*, n. sp. From Spring Hill, on Appomattox River Va.

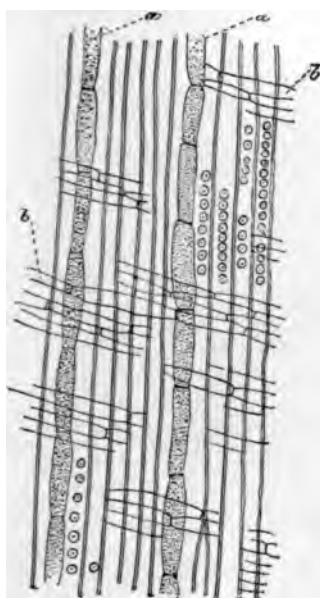
FIG. 1. Radial section. *a, a*, resin-ducts; *b, b*, medullary rays. $\times 67$.

FIG. 2. Transverse section. *a, a*, medullary rays; *b*, fall wood; *c*, spring wood. $\times 67$.

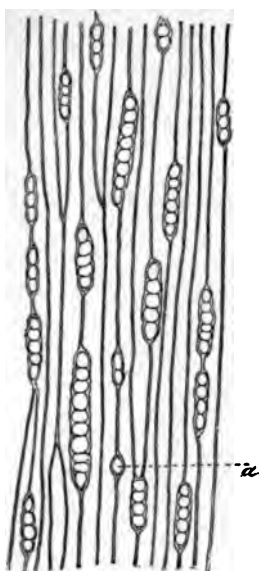
FIG. 3. Transverse section of pith. *a, a*, cells of pith; *b, b*, medullary rays; *c*, tracheids in contact with pith. $\times 67$.

FIG. 4. Tangential section. *a*, medullary ray of single cell. $\times 67$.

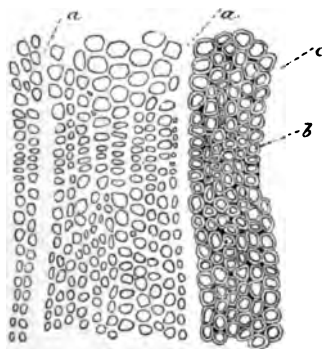
FIG. 5. *Cupressinoxylon McGei*, n. sp. From the new reservoir, Washington, D. C. Radial section. *a*, point at which the structure has disappeared; *b, b*, medullary rays, mostly showing oblong pores. $\times 67$.



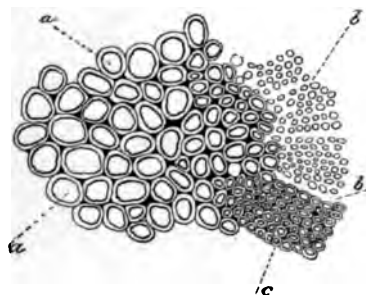
1



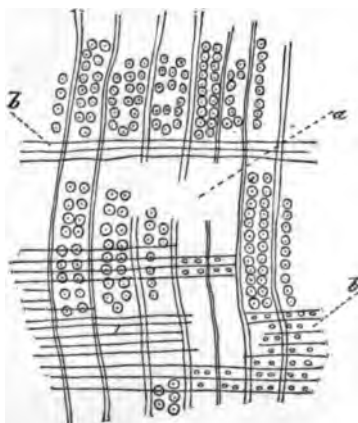
4.



2.



3.



5.

PLATE III.

PLATE III.

1-5. *Cupressinoxylon McGeei*, n. sp. From the new reservoir, Washington, D. C.

FIG. 1. Transverse section showing annual ring. *a*, cells of fall wood; *b*, typical cell of spring wood; *c*, large intercellular space; *d*, *d*, smaller intercellular spaces. $\times 67$.

FIG. 2. Tangential section. *a*, resin-duct; *b*, *b*, bordered pits on tangential walls; *c*, sections of pits on radial walls. $\times 67$.

FIG. 3. Radial section. Same section as Fig. 5, Pl. II. $\times 242$. *a*, *a*, pits on walls of medullary rays; *b*, *b*, pits on walls of tracheids.

FIG. 4. Transverse section further enlarged. *a*, medullary ray; *b*, *b*, cells of spring wood; *c*, section of pits on radial walls; *d*, section of pits on tangential wall. $\times 242$.

FIG. 5. Tangential section. *a*, resin-duct; *b*, *b*, bordered pits on tracheids; *c*, *c*, bordered pits on resin-duct connected by spiral lines.

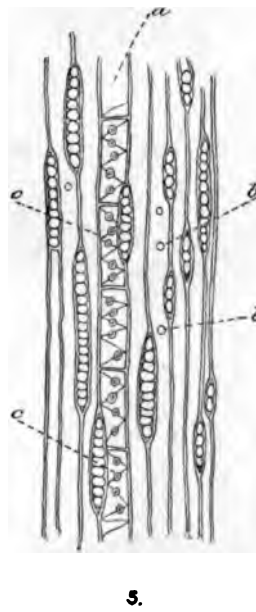
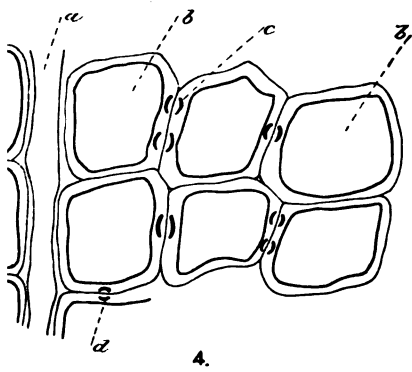
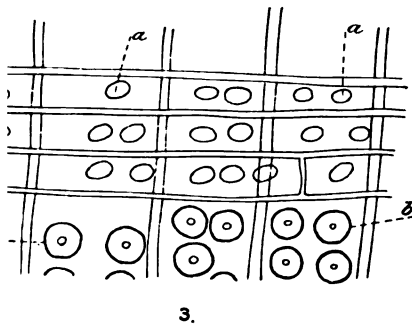
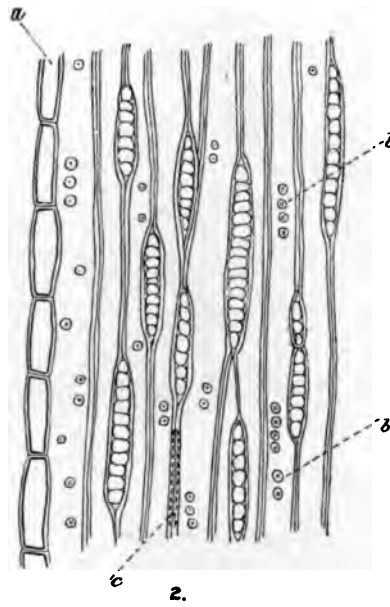
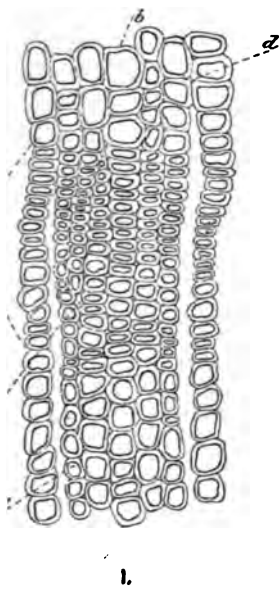


PLATE IV.

PLATE IV.

FIGS. 1-4. *Cupressinoxylon Wardi*, n. sp.

FIG. 1. From Neabsco Creek, Va. Transverse section through annual ring. *a*, cells of fall wood; *b*, cells of spring wood; *c, c, c*, large intercellular spaces. $\times 67$.

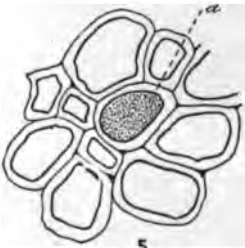
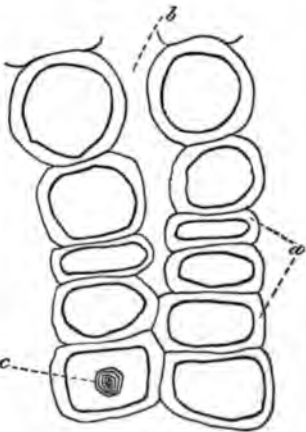
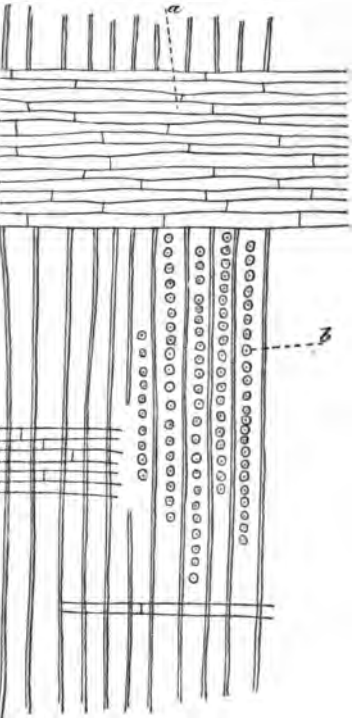
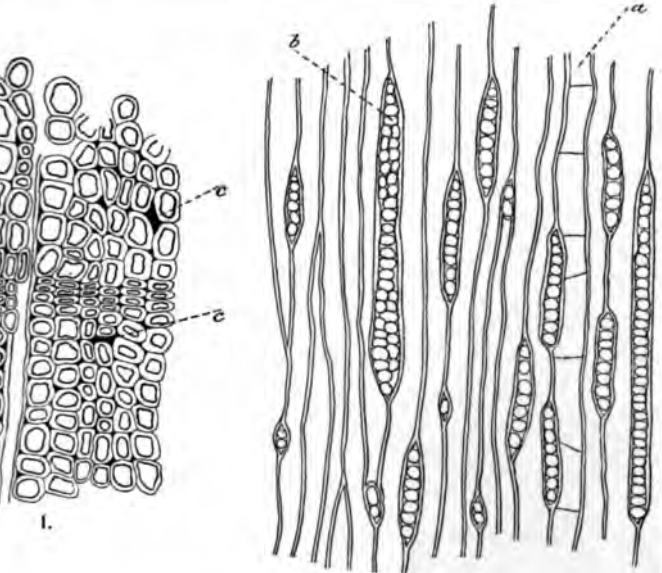
FIG. 2. From cut on B. & O. R. R. Tangential section. *a*, resin-duct; *b*, medullary two cells broad. $\times 67$.

FIG. 3. From cut on B. & O. R. R. Radial section. *a, a*, medullary rays; *b*, single row of pits on tracheids. $\times 67$.

FIG. 4. From cut on B. & O. R. R. Transverse section further enlarged. *a*, cells of small annual ring; *b*, medullary ray; *c*, hexagonal cavity in the silica which fills the cell. $\times 242$.

FIG. 5. *Cupressinoxylon Columbianum*, n. sp.

From Neabsco Creek, Va. Transverse section showing resin-duct, *a*. $\times 242$.



3.

5.

PLATE V.

PLATE V.

1, 2. *Cupressinoxylon Wardi*, n. sp.

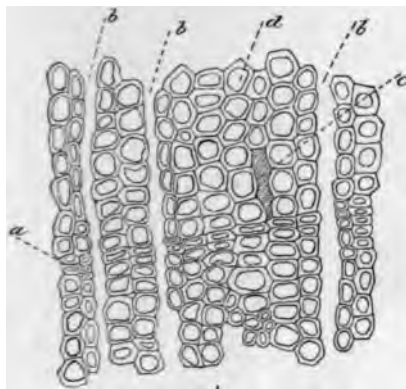
FIG. 1. From cut on B. & O. R. R. Transverse section through annual ring. *a*, cells of fall wood; *b, b, b*, medullary rays; *c*, very large intercellular space. $\times 67$.

FIG. 2. From Neabsco Creek, Va. Radial section. *a*, medullary ray; *b*, tracheid with two rows of bordered pits. $\times 67$.

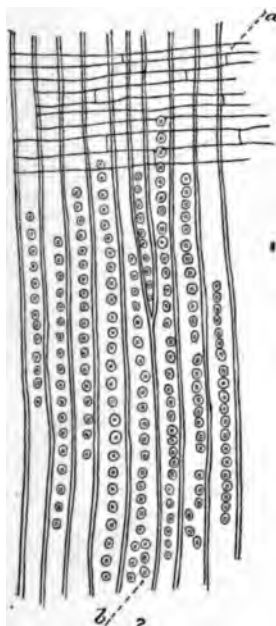
3, 4. *Cupressinoxylon Columbianum*, n. sp.

FIG. 3. From Neabsco Creek, Va. Radial section. *a*, resin-duct; *b, b*, medullary rays. $\times 67$.

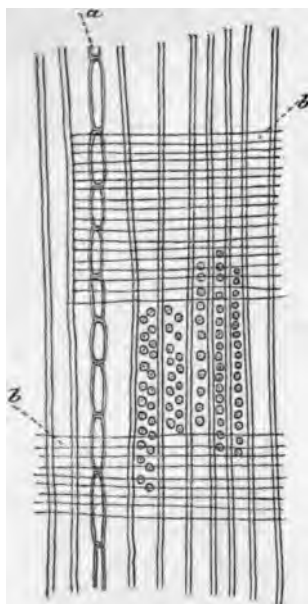
FIG. 4. From Dutch Gap Canal, Va. Tangential section. $\times 67$.



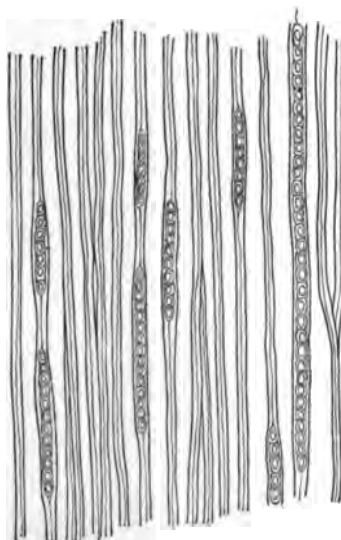
1.



2.



3.



4.

PLATE VI.

PLATE VI.

FIGS. 1-5. *Cupressinoxylon Columbianum*, n. sp. From Dutch Gap Canal, Va.

FIG. 1. Transverse section. *a, a*, medullary rays; *b*, typical tracheids. $\times 67$.

FIG. 2. Radial section. *a, a*, resin-ducts; *b, b*, medullary rays. $\times 67$.

FIG. 3. Transverse section further enlarged. *a*, medullary ray; *b, b*, typical cells of spring wood. $\times 242$.

FIG. 4. Transverse section of resin-duct, *a*. $\times 242$.

FIG. 5. Radial section further enlarged. *a*, cell of resin-duct filled with minute globules of resin; *b*, tracheid with a single row of bordered pits; *c*, tracheid with two rows of bordered pits. $\times 242$.

U. S. GEOLOGICAL SURVEY

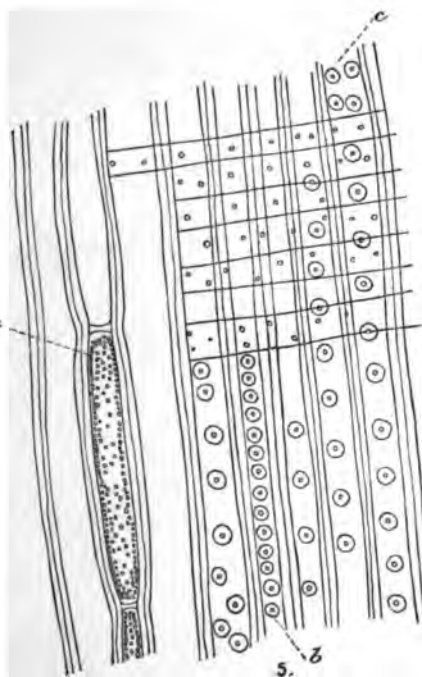
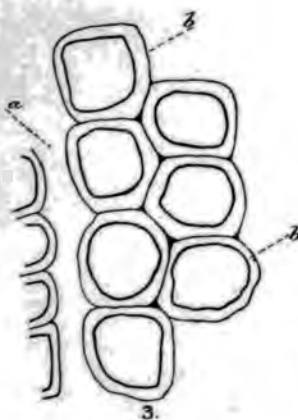
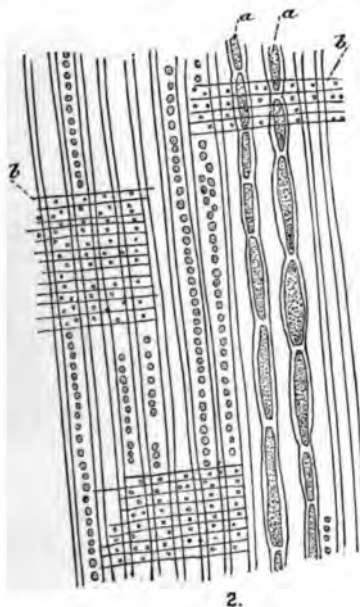
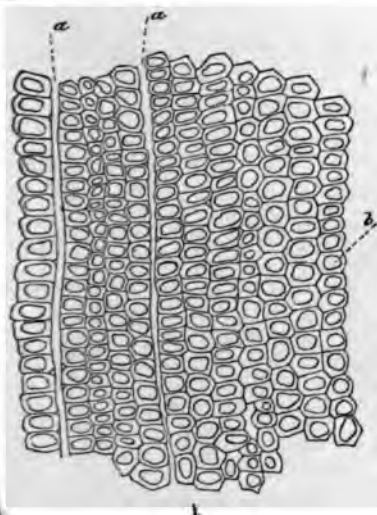
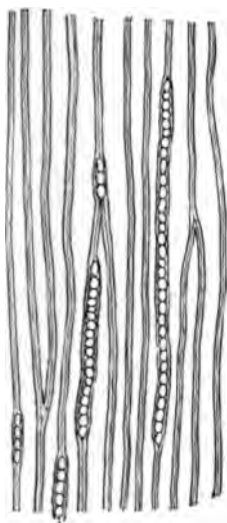


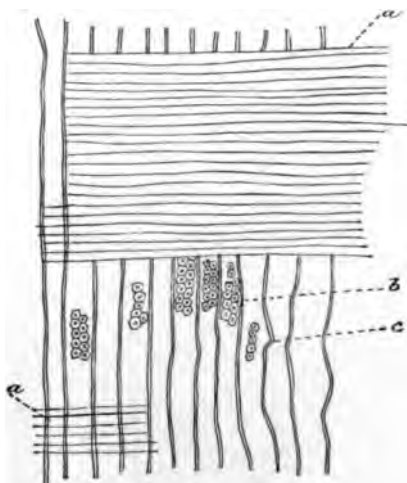
PLATE VII.

PLATE VII.

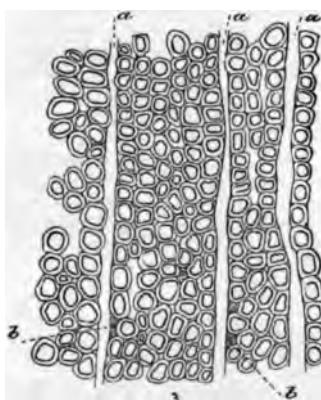
1. *Cupressinoxylon Columbianum*, n. sp. From Neabeco Creek, Va.
Tangential section. $\times 67$.
- 2-5. *Araucarioxylon Virginianum*, n. sp. From Taylorsville, Va.
- FIG. 2. Radial section. *a, a*, medullary rays; *b*, tracheids with two rows of hexagonal pits; *c*, walls of tracheids dislocated by pressure. $\times 67$.
- FIG. 3. Transverse section. *a, a, a*, medullary rays; *b, b*, intercellular spaces. $\times 67$.
- FIG. 4. Tangential section. *a*, sections of bordered pits on radial walls. $\times 67$.
- FIG. 5. Radial section further enlarged. *a*, single row of rounded pits; *b*, double row of hexagonal pits. $\times 242$.



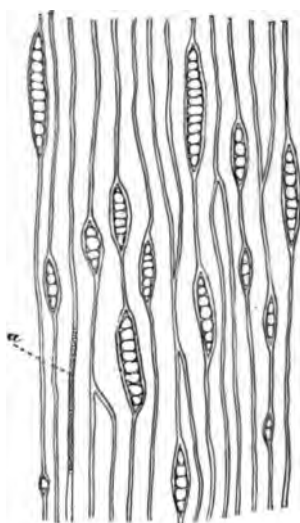
1.



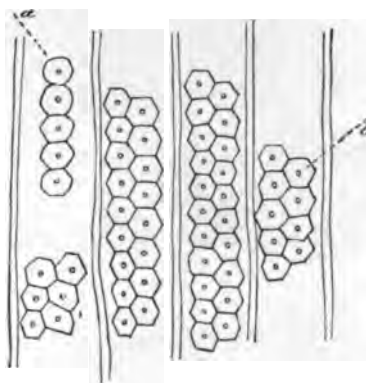
2.



3.



4.



5.

INDEX.

A.	Page.
Abies.....	14
Acacioxylon.....	35
Acerium.....	20
Agricola, early mention of fossil wood by.....	13
Alaska, fossil wood from.....	37
Albinus, description of fossil birch by.....	13
Alnoxyton.....	35
Anabathra, first mention of.....	17
Anacardioxylon.....	34
Ancients, knowledge of, concerning fossil wood.....	12
Antigua, fossil wood from.....	15, 33, 34
Aporoxylon.....	23, 24, 25, 33
Araucaria.....	19
Araucarioxylon.....	23, 35
affinities of.....	35, 50
Heerli.....	35
Virginianum, n. sp.....	50
Araucarites.....	21, 26
Möllhausianus.....	23
Schrollianus.....	25
Aristotle, generatio æquivoca of.....	14
Arundo.....	24
Australia, fossil wood from.....	33
Avicenna, vis lapidifica of.....	14
B.	
Bailey, J. W., on fossil wood from Posun- cula River.....	23
Balbinus, description of specimens by.....	13
Balfour, J. H., on coal of Fordel.....	22
Beck, Richard, on Oligocene from Mitt- weida.....	33
paper by.....	37
Benney, E. W., on coal plants of England.. on structure of Carbonifer- ous plants.....	27 30
Betula.....	14
lignitum.....	27
MacClintockii.....	28
Betulium.....	20, 24
Betuloxylon.....	36
Beust, Fritz, on fossil wood of Greenland..	35
Blanchenhorn, Max, paper by.....	37
Boyle, on process of fossilization.....	13
Bradea.....	22
Brazil, fossil wood from.....	33
Bromel, on process of fossilization.....	13
Brongniart, on Sigillaria elegans.....	18
Brown, Heinrich Georg, papers by.....	31

C.	Page.
Calamites.....	31
Calamodendron.....	31
Calamopitys.....	23
Calamopteris.....	23
Capparidoxylon.....	35
Carruthers, William, on Cycadean stems of Britain.....	23
on petrified forest near Cairo.....	29
Cassioxylon.....	34
Cedroxylon.....	28, 30
Cladocupressoxylon Protolarix.....	33
Cladoxylon.....	23
Claypole, E. W., on fossil wood from Car- boniferous of Ohio.....	37
on fossil tree from Ohio ..	31
Clethrites.....	13
Colopoxylon.....	26
Constantinium.....	27
Conwentz, H., on Calistoga fossil wood.... on fossil wood from Pata- gonia.....	29 36
on fossil wood of Berlin land office.....	32
on fossil wood of Karlsdorf on the petrified wood of the North German Diluvium.....	32 31
Copper Island, fossil wood from.....	37
Corda, August Joseph, "Flora der Vor- welt".....	19
Cormocupressoxylon Protolarix.....	33
Cornoxylon.....	32
Cotta, C. Bernhard, "Die Dendrolithen".....	17
Cramer, C., fossil wood of Arctic Zone.....	27
Cuba, fossil wood from.....	33
Cupressinoxylon.....	21, 27
affinities of.....	35, 36, 43
Brevorni.....	28
Columbianum, n. sp.....	49
definition of.....	44
dubium.....	28
erraticum.....	37
glyptostrobinum.....	36
McGeel, n. sp.....	46
Mercklini.....	36
polyommatum.....	28
Protolarix.....	33
pulcellum, n. sp.....	45
pulchrup.....	28
taxodioides.....	29

INDEX.

	Page.
ssinoxylon uniradiatum.....	32
ucranicum.....	28
Wardl, n. sp.....	48
soxylon.....	28, 30

D.

ylon.....	25, 26, 33
from Prince Edward Island.....	22
antiquus.....	37
Edvardianum.....	30
materiarium.....	30
Newberryi.....	37
a, fossil wood from.....	37
tia, plant beds of.....	12
n, J. W., Devonian and Carboniferous plants.....	25
flora of the Devonian.....	25
fossil wood from Gaspé.....	23
fossil wood from Prince Edward Island.....	22
on affinities of Sigillaria Calamites and Calamodendron.....	30
on plants of Erian and Silurian formations.....	33
on plants of Gaspé.....	24
on plants from lignitic tertiary.....	30
pre-Carboniferous flora.....	25
synopsis of Carboniferous flora in Nova Scotia.....	26
vegetable structures in coal.....	24
ylon.....	27
yoxyton.....	35
.....	13

E.

cyton.....	34
fossil.....	13
fossil forests of.....	13
fossil wood from.....	18
ld, Edouard D', paleontology of.....	27
er, Stephen, "Synopsis Coniferales....."	13
mites.....	20
a.....	16
.....	19

F.

lites.....	32
lm.....	20
ohannes, examinations of fossil wood.....	34, 36
fossil wood of West Indies.....	34
on fossil coniferous wood.....	33
on wood opal of Hungary.....	35
studies on fossil wood.....	32
on.....	34, 35
e, William M., on age of Potomac tion.....	38
mycelium of fossil.....	32

G.

	Page.
Gazlay, Rev. Sayrs, papers by.....	18
Gesner, description of specimens by.....	18
Glyptostroboxylon.....	36
Goldenberg, Friedrich, on Sigillaries and Selagines.....	28
Good Hope, Cape of, fossil wood from.....	18
Göppert, H. R., amber flora.....	19
first genus of dicotyledons founded by.....	19
"Flora der Gypsformation".....	19
"Flora des Uebergangesbirge".....	21
flora of Aachen.....	19
flora of the Permian.....	25
monograph of the Coal-ferns.....	12, 29
on fossil Cyndadaceae.....	19
on fossil wood from New Mexico.....	28
on Taxites scalariformis.....	19
on Tertiary flora of Java.....	22
on Tertiary flora of Silesia.....	21
Göppert, H. R., and Menge, A., flora of the amber.....	24
Göppert, H. R., and Stenzel, C. G., on Medullosae.....	22

H.

Hauera.....	24
Americana.....	24
Helictoxylon.....	24
Henkel, early work by.....	15
Hildebrand, F., on distribution of Conifers.....	25
Hire, de la, description of specimens by.....	14
Hitchcock, Edward, brown coal of Brandon, Vt.....	21
Hofmann, H., works by.....	36
Holmes, W. H., on fossil forest of Yellowstone Park.....	29
Hook, Robert, description of specimens by.....	13
Hooker, J. D., on structure of Lepidostrobi on structure of Stigmaria.....	28
Hutton. (See Lindley & Hutton.)	

I.

Imperatus, on process of fossilization.....	13
India, fossil wood from.....	33
Internal structure, value of study of.....	11
Italy, plant beds of.....	12

J.

Japan, fossil wood from.....	33
Java, fossil wood from.....	33
John, J. F., origin and nature of amber.....	16
Jordania.....	35
Junghuhnites.....	22

K.

Kentmann, on process for producing fossils artificially.....	13
Kieser, on organization of plants.....	15
Klippsteinia.....	24

	Page.	O.	Page.
coides	19		
, "Araucarien d. Rothlie-	27	Organic remains, kinds of, in Potomac for-	40
genden "		mation	39
"bayrische Tertiärhöf-	37	mode of occurrence of	14
zer"		Ostrya	
fossil Coniferae	28		
on structure of living and			
fossil Coniferae	26		
leontology of Russia	19		
		P.	
L.		Paleobotany, lines of investigation fol-	
verl.	37	lowed in	11
.....	34, 35	structural	11
.....	17, 23, 24, 31	superficial	11
.....	31	value of, to stratigraphy	11
o, on fossil fruits of Bran-	22	Palmoxylon	33, 34
d, first use of term Lithox-	14	Parkinson, James, "Oryctology"	17
.....	35	Pattinson, H. L., works by	17
.....	40	Perforatus angularis	33
tion of, for study	40	punctatus	33
atic description of	41	Petrified wood, earliest published accounts	
on, "Fossil Flora of Great	34	of	12
.....	17	Peuce	17, 24
.....	35	biarmica	19
.....	14, 15	tanaitica	19
fossil wood from	37	Phegites	13
flood theory of	14	Philippines, fossil wood from	37
		Physematoptys	21
M.		Pinites	21, 26
us, earliest account of petri-		first mention of	17
fied wood by	13	aquegranensis	19
virtus formativa of	14	biarmicus	19
very of pits on wood cells		Brandlingi	18
.....	16	cavernosus	28
age of Potomac formation	38	gypsaceus	19
fossil forest in California	29	medullaris	31
early work by	15	pauciporosus	28
fossil palms	21	Protolarix	33
y description of specimens		succinifer	20
.....	13	Withami	18
age of Potomac formation	38	Pinus	14, 19
composition of Potomac		Johnseni	32
formation	38	MacClurii	28
.....	26	Pissadendron	21
.....	21	Pitus	17
.....	22	Pityoxylon	28, 30
.....	14	inaequale	37
.....	18	Krausei	37
.....	26	microporosum	36
		Plataninum	20
		Podocarpium dactyloides	25
		Populus	30
		Potomac formation, age of	38
		distribution of	39
		exposures of	40
		geological and geographical dis-	
		tribution of	38
		Protopytis	21
		Prototaxites	24, 25, 33
		Psarolithes	15
		Psaronius	22, 26
		Psilophyton	24
		Q.	
		Quercinium	19, 20, 31, 34
		Quercites	31
		Quercus	14

R.		Page.		Page.	
Benoist, B., on <i>Sigillaria spinulosa</i>	31	Stigmaria	23, 24, 25	Syringoxylon	25
on stems of the Carboniferous	31				
on structure of <i>Asteromyalon</i>	36	T.			
<i>Rhinobalanoxylon</i>	33	<i>Tanioxylon</i>	24	<i>opercoides</i>	27
<i>Rhinocupressinoxylon</i>	32, 34	<i>Taxites</i>	21	<i>Taxoxylon</i>	23, 29
<i>Protolarix</i>	33	<i>Taxus</i>	19	<i>Tellihatcheites</i>	27
<i>Rhisonium</i>	34	<i>Thuloxylon</i>	24		
Rhode, on fossil wood	16				
Richter & Unger, "Paleontology of the Thuringian Forest"	23	U.			
Rogers, W. B., on the Potomac formation	38	<i>Ulmium</i>	25	<i>Ulodendron</i>	24
<i>Rohlfia</i>	34	Unger, Franz, " <i>Chloris protegnus</i> "	29	<i>Flora of Glatschenberg</i>	29
Roman Empire, plant beds of	12	fossil forest near Cairo	29	fossil plants from New Zealand	25
Roque, Abbé de la, description of specimens by	14	"Genera et species plantarum fossilium"	29	synopsis of fossil plants	19
S.		V.			
<i>Sapotoxylon</i>	34	Vater, H., works by	28		
Schaeffer, George C., fossil wood from the Colorado Desert	23	Voigt, Johann K. W., description of <i>Paeolites</i> by	25		
Schenk, A., on Cotta's species of <i>Perforatus</i>	38	Volkman, Georg Anton, early work by	15		
on fossil wood from India	38				
on fossil wood of the Libyan Desert	34	W.			
Scheuchzer, Johann Jacob, "Herbarium Diluvianum"	14	Walch, early work by	25		
Schlotheim, E. F. von, on fossil wood	16	Ward, Lester F., "Sketch of Paleobotany"	12		
Schmalhausen, J., on Tertiary flora of Russia	36	Weber, C. Otto, on Tertiary flora of the Lower Rhine	21		
Schmid & Schleiden, "Natur der Kieselhölzer"	22	Weppen, J. A., work by	15		
<i>Schmidellopsis</i>	34	West Indies, fossil wood of	24		
Schröter, J. S., early work by	15	Westphal, description of specimens by	14		
Schroeter, Carl, on Arctic fossil wood	31	Williamson, W. C., list of principal works by	29		
<i>Sequoia</i>	36	on organization of fossil plants of the Coal Measures	23, 27		
<i>Sigillaria</i>	24, 27, 31	on value of evidence obtained from internal structure	12		
<i>elegans</i>	18	Witham, Henry T. M., works by	14		
Silicified wood, occurrence of, in Potomac formation	40	Worman, description of specimens by	12		
preparation for study of	40				
systematic description of, from Potomac formation	41	Z.			
Solms-Laubach, works by	36	<i>Zamites</i>	25	<i>Zittelia</i>	24
<i>Spiroplitis</i>	21				
Sprengel, Anton, work on <i>Paeolites</i>	16				
<i>Stelachites</i>	13				
Stelluti, Francisous, first book devoted to fossil wood	13				
Stenzel, C. G., on fossil palms	21				
"Staarsteine"	22				
<i>Stenzelia</i>	26				
<i>Staubia</i>	35				
<i>Sternbergia</i>	25				

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 57



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890





1



Alluvium



UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

GEOLOGICAL RECONNAISSANCE

IN

SOUTHWESTERN KANSAS

BY

ROBERT HAY



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



CONTENTS.

	Page.
er of transmittal.....	9
duction by W J McGee	11
ral statement.....	15
geologic formations.....	18
Carboniferous.....	19
ura-Trias	20
Cretaceous.....	27
The Dakota.....	27
The Fort Benton.....	27
The Niobrara	30
The post-Cretaceous erosion	31
Tertiary	31
The Tertiary grit	32
The Tertiary marl.....	35
The Tertiary erosion.....	36
Quaternary.....	38
The gumbo	38
The earlier gravel.....	39
The loess	41
The later gravel	42
The alluvium	43
Conclusion	45
The general results.....	45
The source of the Tertiary conglomerates.....	45
The question of Tertiary shores	46
The tripartite erosion	47
Economic geology	48



ILLUSTRATIONS.

	Page.
ate I. Geologic map of southwestern Kansas.....	Frontispiece.
II. Ideal section from the Arkansas River to Colorado line—Section from Wellington to the Cimarron River—Section from north to south through Barber County.....	14
ig. 1. Section five miles south of Wichita	19
2. Biscuit shale	20
3. Red rock buttes, Gypsum Hills.....	23
4. Mansard buttes, Gypsum Hills.....	24
5. Section of the Dakota strata	28
6. Section on Spring Creek, Meade County	28
7. Section across a small ravine, Harper County	33
8. Section down the east side of a small ravine in Harper County	33
9. Section near Wichita.....	34
10. Section in Meade County	34
11. Section on Kiowa Creek, Comanche County.....	36
12. Section across Saw Log Creek, north of Dodge City	36
13. Section on south side of Saw Log Creek.....	36
14. Section in Norton County.....	37
15. Tertiary bluffs on the Arkansas River.....	37
16. Section in Hamilton County	38
17. Section in Hamilton County	38
18. Red Bluff on Bluff Creek.....	39
19. Section at cutting on Santa F6 Railway, Wellington, Kansas	40
20. Loess Bluffs on Medicine River.....	42
21. Section across the Arkansas Valley	47

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
POTOMAC DIVISION,
Junction City, Kans., May 24, 1889.

SIR: I have the honor to transmit to you, by direction of Mr. W. J. McGee, chief of this division, a report of a reconnaissance in southwestern Kansas, made in the summer of 1885, with some additional matter incorporated therewith, as the result of other journeys into the same region made particularly for the purpose of determining the geological relations of the recently discovered beds of rock-salt and of continuing the observations into Colorado. The value of the work is enhanced by the kind encouragement received during its progress from my immediate chief, Mr. McGee. It is also proper to say that valuable aid was received from Hon. J. R. Mead, of Wichita, J. H. Simmons, of Wellington, and other citizens at Harper, Medicine Lodge, Kingman, Hutchinson, and Dodge City. The Atchison, Topeka and Santa Fé, the Southern Kansas, and the Missouri Pacific railways gave transportation facilities. Engineers of these roads, and also of the "Frisco Road," kindly supplied me with tables of elevations on their newly surveyed routes.

The determination of fossils has been made by Drs. C. A. White and W. H. Dall.

I am, sir, yours respectfully,

ROBERT HAY,
Assistant Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.



INTRODUCTION.

By W J MCGEE.

During the period of active prosecution of geologic surveys under State auspices within the Mississippi Valley, the structure of that region was definitely made out, and its formations were correlated with greater or less precision with those of the Atlantic Slope; but these State investigations were not carried forward to the region then commonly, as now occasionally, known as the Great Plains. During the partly contemporaneous and partly subsequent period of active exploration and scientific investigation of the western territories by the Federal Government, the geologic phenomena of the Rocky Mountain region were elucidated, and certain of the formations found there were correlated upon purely paleontologic grounds with those of the East and the middle West—the broad Mississippi Valley. But although a score of geologists traversed the Great Plains from time to time, and although half a dozen official and amateur geologists have systematically studied different portions of the region, there yet remains a great area, comprising considerable portions of Dakota, Nebraska, eastern Colorado, Kansas, Indian Territory, and Texas, within which little is known of the geologic structure through direct observation by trained specialists. The indefiniteness of knowledge concerning the formations of this great area and their distribution is strikingly indicated by the discrepancies in the various geologic maps covering it. There is thus a hiatus in geologic exploration within the Great Plains, which it is desirable to close.

The geologic history recorded in the Paleozoic rocks of the Mississippi Valley and in the degradation of the same region after its emergence, is exceedingly simple: During the Paleozoic, deposition was slow, and the formations are thin, remarkably uniform, and approximately conformable throughout great areas, and are indicative of slight and slow alteration in continental configuration; and the emergence of the land at the close of the Paleozoic was a simple vertical movement effected without material disturbance of the strata. During the Mesozoic there were occasional eras of quiet deposition of shoal water sediments, probably at one time extending as far east as the Mississippi

River from the confluence of the St. Croix southward; but during the greater portion of post-Paleozoic time the region has been above the sea, and yet so slightly elevated and so slightly disturbed by tectonic movements that degradation has reached but a small fraction of that suffered by most portions of the terrestrial surface. In the Rocky Mountain region, on the contrary, the various geologic phenomena record a complex history. During the Paleozoic, sedimentation was rapid but irregular, betokening great concurrent geographic changes; certain of the Mesozoic formations are of enormous thickness, while at other horizons occur great unconformities which together indicate repeated and important changes of sea and land. During portions of Cenozoic time, deposition was rapid, while during other epochs the land stood at such great altitude above the waters into which its débris was carried that erosion was wonderfully active; and the latest records inscribed in the rocks of the region are of almost unparalleled degradation, which during a brief period has removed many times as much matter from the surface as has been removed from the Mississippi Valley during its untold ages of slow degradation. There is thus a discrepancy between the testimony of the rocks in the Mississippi Valley and that of the Rocky Mountain phenomena which it is desirable to harmonize by studies in the intervening region, in order that geologic conceptions may be unified and geologic interpretation reduced to a common standard.

In the eastern United States there is a great blank in geologic history at the close of the Paleozoic, for the Triassic rocks of the east have not yet been, and perhaps never will be, fully interpreted. In the Mississippi Valley there is a great blank in the same portion of the geologic record, for the Mesozoic outliers upon the Paleozoic terraces, extending far towards the Mississippi River, represent not the commencement, but rather the close, of the Mesozoic. And in the Rocky Mountain region the Triassic rocks generally leave unrepresented a considerable interval between the Paleozoic and Mesozoic systems, and in their structure, composition, color, dearth of fossils, and many other respects fairly bristle with problems yet unsolved. So there is a hiatus in the American geologic section, and in the time it represents, which it is desirable to bridge; and since there occur within the Great Plains extensive rock-masses which have been tentatively referred by some geologists to the Paleozoic and by others to the later Mesozoic, it seemed probable when this reconnaissance was projected that by investigation there the blank might be filled.

The superficial deposits of the earth are numerous and variable and difficult of interpretation. They have generally been classified by conditions of genesis. Now the glacial drift of the northern United States has been extensively studied and is fairly understood; the loess extending from near the margin of the glaciated area towards the Gulf presents a riddle yet but partly read; the alluvial and littoral deposits of the Mississippi embayment are not fully interpreted;

the products of secular rock disintegration under various conditions have only recently begun to receive serious attention; the great alluvial fans and taluses fringing the Rocky Mountain region, which have been accumulating ever since the emergence of the land or the birth of the mountains, have embarrassed American geologists just as their European homologue—the “Nagelfluh” etc.—has mystified the geologists of the Old World; and the superficial deposits upon the Plains, which have some of the characteristics of all these accumulations, present a many-sided problem whose solution will unquestionably facilitate the interpretation of each of the clearly differentiated deposits. Thus there is an immeasurable blank in our knowledge of composite superficial deposits which investigation in the Great Plains promises to fill.

There have been found in Petite Anse and adjoining islands on the Louisiana coast extensive deposits of salt associated with gypsum, the extraction of which is rendered difficult by the depth beneath tide. Now, reports of the occurrence of salt and extensive beds of gypsum have gone out from western Kansas, Indian Territory and contiguous parts of Colorado and Texas, and it is important to ascertain whether these reports are well founded and whether the occurrence of the minerals indicates the existence of either the same or equally extensive deposits of rock salt in these localities, for the obstacles to ready extraction met at Petite Anse Island do not exist there.

Carbonaceous shales and lignites are of frequent occurrence in portions of the Great Plains, and have led to brilliant expectations among the citizens of Nebraska, Kansas, eastern Colorado and Texas, and to costly prospecting and extensive investments in property, and it is desirable that the questions as to the existence within these States of lignites or true coals, and of their position, extent and value if found, should be definitively answered at an early day.

With the westward extension of settlements upon the plains the different occupations to which the various portions of the region are adapted—agricultural, pastoral, etc.—have come to overpass their natural limits. Thus agriculture presses upon the zone naturally adapted to stock-raising, and stock-raising presses upon the zone of variable climate in which the profits of a successful lustrum are swallowed up in the losses of one unsuccessful year. Now, in order that either agriculture or stock-raising shall reach the best results, it is essential that the character of the soil and its adaptability to given products be understood, that the capabilities of irrigation by surface waters be considered, that the possibilities of artesian water supply for irrigation and for other uses be determined, and that many other relations between the rocks of the earth and present and prospective industries and enterprises be ascertained.

These and other considerations have led to the inauguration of systematic investigation in the region described in the following pages, which comprise the preliminary report of a rapid reconnaissance.

The scientific and economic questions involved have not, however, been fully settled by the reconnaissance, but it is believed that Mr. Hay's report will be found to contain valuable contributions to our knowledge of a region important but little studied.

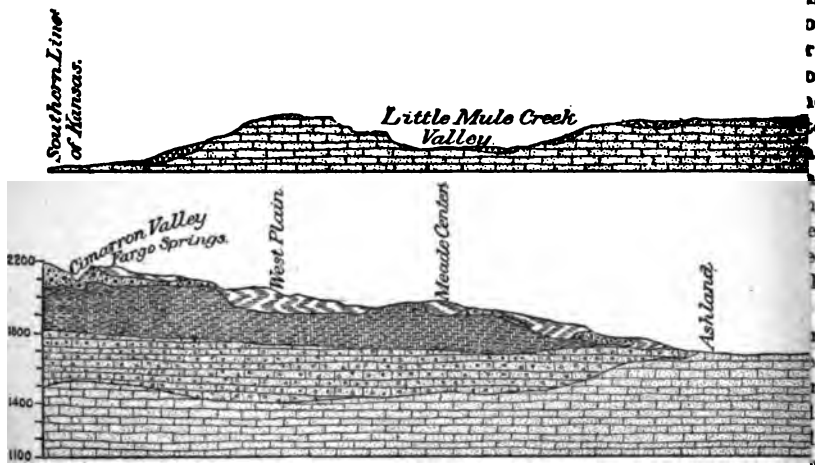
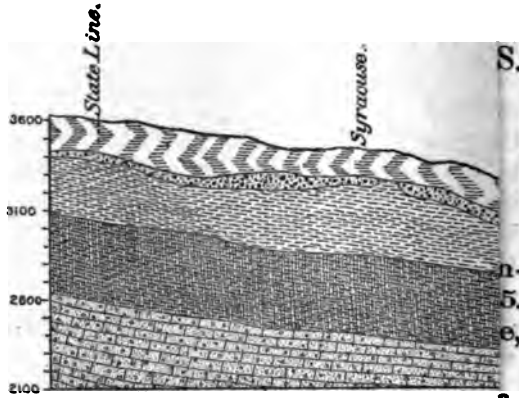
Although no attempt has been made to finally classify the formations examined or to trace their distribution in detail, the provisional cartography of the region is a substantial addition to American geology: The limits of the Carboniferous group of rocks, within which valuable coal beds unquestionably exist, have been defined; the structure, mineral contents, stratigraphic relations, and geographic extent of the puzzling gypsiferous "Red Rocks," which have been variously referred to the Permian, the Dakota formation of the Cretaceous, and to several intermediate horizons, have been ascertained, and the uncertainty as to their age and position has been materially narrowed; the character of the lignitiferous Cretaceous deposits has been made out, and the different formations have been correlated tentatively with those of the montanic region; the Tertiary formations have been defined; and several distinct superficial deposits have been discriminated, and their genesis has been determined in part.

Practical considerations prevented the extension of the reconnaissance into the montanic region, within which the geologic agencies have been so much more active than in the little disturbed Mississippi Valley; but throughout the investigation the agencies and processes have been considered as the products were studied, the significance of unconformities has been appreciated, and some progress has been made in reconciling the discrepant records of the two widely diverse geologic provinces.

The correlation of the formations and the final interpretation of the early Mesozoic passage beds were unfortunately impeded by the dearth of fossils, and little has been done in this direction.

Although the questions as to the character of the soils, the extent and value of the salt, gypsum and lignites, the irrigation problem, the artesian well problem, and the various other economic questions considered, have not been specifically answered, the salient mineral characters of the rocks have been ascertained; and with the profiles of the country and the fall of streams, the composition and attitude of the strata upon which the artesian flow depends, etc., have been set forth in general terms, and a substantial foundation for more detailed future investigation has been laid.

It may be mentioned that Mr. Hay has been engaged in amateur geologic studies in Kansas for some years, and thus has brought to his task general familiarity with the phenomena of the region and many valuable data which could have been gained otherwise only at the cost of much time and labor; and it is just to add that although the expenses of the journeys were borne by the United States Geological Survey, his own labor and that of his assistant were performed gratuitously.



PLEISTOCENE.



LOESS.



GRAVEL.



GEOLOGICAL RECONNAISSANCE IN SOUTHWESTERN KANSAS.

By ROBERT HAY.

GENERAL STATEMENT.

This report relates to a reconnaissance which was made under instructions from the chief of the Potomac Division, dated May 27, 1885. Those instructions, as far as they directly relate to the work to be done, were as follows:

We need a section through Kansas from east to west which shall exhibit the relations of the various formations of the State, particularly those of post-Carboniferous age. I think it possible to construct such a section along the Arkansas River from the border of the Carboniferous in about longitude 98° W. to the eastern line of, or perhaps one or two hundred miles within, the State of Colorado. In case there are not sufficient exposures there, some other line might be chosen. In the collection of material for the section it is desirable that attention should be given not only to the eastern margins of the Mesozoic and Cenozoic formations as they now exist, but to the erosion that the formations have suffered about their peripheries, in order that the positions of the successive shores of these ages may be determined. The formations themselves and the contained fossils should also be subjected to careful examination in order to ascertain, if possible, whether they were deposited in saline, brackish, or fresh waters. The physical condition of the sediments should also receive attention, since such condition may indicate the depth of the waters in which they were laid down and the positions of the shores.

The phenomena due to post-Pliocene agencies should also be studied. There is in Texas and in Indian Territory, and, so far as I can learn, in Kansas, a superficial deposit of gravel and siliceous pebbles. A related gravel also occurs in the northern portion of the great plains in western Nebraska. The origin of this gravel (including the sources of the material and manner of its distribution) should be ascertained, and also its relations to present drainage, to "second bottoms," and to any other fluvial or littoral terraces that may exist in the region.

Certain limitations as to cost accompanying these instructions, the journey made could be only a reconnaissance. It lasted seven weeks. Since then I have spent ten days in the neighborhood of Pueblo, and have also made another brief trip to Barber County, Kansas, and several trips have since been made into different parts of the region. All of these have added to the material used in this report. The actual routes taken will appear farther on and are indicated on the map.

The region explored has been somewhat of a terra incognita, geologically. Though several statements have been made concerning it, some of them semi-officially, yet no definite account of its geology has been made public, and it is not known that any reliable geologist has done more than make a hasty trip to some part of it.

There has been a general impression among scientific men in Kansas that an irregular line slanting from east of north to south of west, and crossing the thirty-ninth parallel near its intersection with the Sixth Principal Meridian, approximately indicates all across the State the eastern boundary of the Cretaceous formations, the lowest of which in Kansas—the Dakota—has been found particularly rich in fossil leaves of dicotyledonous plants. This formation is seen in many places resting directly on rocks well known to be of Carboniferous age. Carboniferous strata, yielding good building stone—the so-called magnesian limestone—appear all across the State from the fortieth to the thirty-seventh parallel, and are known to be continuous both north and south beyond the boundaries of the State. It has been presumed that the Dakota was also continuous southward across the Arkansas River to and beyond the State line, this opinion having been formed without actual observation by geologists, mainly because red sandstone rocks were reported to exist in southern Kansas and Indian Territory.

It was also assumed that the Benton and Niobrara epochs are represented with a still wider development south of the Arkansas. In the Northwest it has been known that Tertiary deposits have covered the Cretaceous, and these deposits have usually been referred to as Pliocene. Prof. B. F. Mudge many years ago suggested that some part of this Tertiary covering was possibly Miocene, as also did Prof. H. D. Cope; but they gave no stratigraphic descriptions upon which distinction of the rock masses could be based. From the trend of the Tertiaries in the northwestern counties—north of east to south of west—it was inferred that there could be little or no development of these formations south of the Arkansas River, where it was supposed the Cretaceous deposits extend to and beyond the Colorado line. As will appear later, these assumptions as to both Cretaceous and Tertiary were erroneous.

In the years 1884-'85 numerous mammalian fossils were found in northwestern Kansas (*Aphelops*, *Camelus*, etc.) and the Tertiary beds yielding them were thereby identified as the Loup Fork, which Prof. Cope has pronounced to be of Miocene age. A little later, in a "Preliminary Report on the Geology of Norton County,"¹ made to the Kansas Academy of Science, November 21, 1883, I gave a description of the stratigraphic relations of the Loup Fork to the newer Tertiary above it and the Cretaceous (Niobrara) below it. It was then shown verbally and by diagrams that the Cretaceous strata had been extensively eroded before the deposition of the Loup Fork, and that the Loup Fork had in its turn been eroded, largely on the same lines, before the deposition of the later Tertiary, which was pronounced provisionally to be the Equus beds of Cope. The erosion since has also been nearly on the same lines as the pre- and mid-Neocene. This report will show that these distinctions obtain extensively south of the Arkansas River.

¹Trans. Kansas Acad. Sci., Vol. IX, 1885, pp. 17-24; and also published separately.

In 1866 Prof. G. C. Swallow described as "Triassic" what is now known as the Dakota, and F. H. Bradley's geologic chart of 1875 marks the same area as Jurassic. As this is now known to be erroneous for the region north of the Arkansas River to the Nebraska line, it was assumed that it was also wrong for the territory south of that river, where the Jura-Trias has been affirmed to exist both by Le Conte and Dana. The explorations of this summer verify the statements of these authors, which were probably made on the authority of Dr. George Shumard's descriptions of the gypsiferous deposits of the Red River. Marcy's Report of the Exploring Expedition of the year 1852, the extension of those deposits north of the Canadian being known and referred to as reaching to the Arkansas. By reference to the map it will be seen that the Jura-Trias covers a large, irregular triangular area extending over several counties.

The routes actually traveled in this investigation lie mostly within the great bend of the Arkansas River, i. e., south and west of it. Some examinations of outliers of the Tertiary formations and of the loess were made on the east of the river near Wichita. In this neighborhood the Tertiary deposits hereinafter called the Tertiary marl and the Tertiary grit were found over a limited area resting on rocks apparently of Permian age. Some exploration was also made from Winfield, where the so-called magnesian limestone is extensively quarried for building purposes, along the line of the Southern Kansas Railway westward to the river. Crossing the river, the line of railway was followed through the counties of Sumner and Harper, with some divergence north and south at the county seats, Wellington, and Harper. From Harper, then the terminus of the railway, the route taken was circuitous to Medicine Lodge, where bad weather occasioned some delay, though a portion of the time was utilized in short journeys to the northern part of Barber County and southwest to the Gypsum Hills, and southeast to the so-called Cedar Mountains. Resuming the forward route, the western part of Barber County was passed through, and northern Comanche (since organized as Kiowa County), Edwards and Ford Counties, to Dodge City. The investigations thence were north of the river to the Colorado line, the last thirty miles, however, giving a mere glance at the geology, as immediate return from this point became a necessity. It will be seen from the map that the Cretaceous formations appear in this region as a fringe of bluffs, the higher ground behind being of Tertiary age. The river was crossed at Lakin and passing through the sand hills which bound the south side of the river valley we crossed the high prairie to the North Fork of the Cimarron. Passing down the stream for some miles we crossed the divide of the South Fork, or main river, down which the route led for about twenty-five miles to the new town of Fargo Springs, in Seward County. In all this region south of the river the Tertiary deposits and sand hills composed the entire geological phenomena. Proceeding eastward, out-

crops of Cretaceous formations were found when the middle of Meade County was reached. The return journey through Clarke County touched the former route at Coldwater, in Comanche County, and came back by a more southerly route to Medicine Lodge, whence the journey to Wichita was made more rapidly through Kingman and Sedgwick Counties by stage and railway.

The basis for the accompanying map is the United States Land Office map of Kansas. For the topography, as shown in the sections, elevations furnished by the engineers of the Atchison, Topeka and Santa Fé, and the Southern Kansas Railways have been used. Some observations with the aneroid barometer, where return to a starting point was possible, as in Barber County, have given results which may be regarded as approximately correct. For the other districts away from the railways estimates only were possible, but these were made with as much accuracy as the nature of the circumstances permitted.

The geology of the northeast parts of the region, as shown in the map, is taken from maps of the Kansas State Board of Agriculture, prepared by Prof. B. F. Mudge and Prof. O. H. St. John; but my own explorations and observations partially confirm them. The extreme southwest and parts north of the Arkansas River in the west, marked Tertiary, are so indicated for the first time, as a legitimate inference from the observations and inquiries made during the reconnaissance.

The region of the exploration as shown on the map is included between the ninety-seventh and one hundred and second meridians, and covers little more than a degree of latitude, its southern limit being the southern boundary of the State, 37° N., and extending in the Arkansas Valley north of the thirty-eighth parallel.

THE GEOLOGIC FORMATIONS.

The first investigations of the reconnaissance were made in formations of Tertiary and Quaternary age, but the general development of strata on the journey westward being in the ascending geologic order, it is deemed best to discuss their development in that order. In their natural relations the formations examined are—

- | | | |
|---------------------|---|----------------------------|
| | { | The Alluvium. |
| | { | The Later Gravel. |
| 1. Quaternary | { | The Loess. |
| | { | The Earlier Gravel. |
| | { | The Gumbo. |
| 2. Tertiary | { | The Tertiary Marl. |
| | { | The Tertiary Grit. |
| 3. Cretaceous | { | The Niobrara formation. |
| | { | The Fort Benton formation, |
| | { | The Dakota formation, |
| 4. Jura-Trias. | | |
| 5. Carboniferous. | | |

CARBONIFEROUS.

The Carboniferous strata (sometimes denominated Permian or Permo-Carboniferous) were observed only as a starting point. Near Wichita they were found dipping westward towards the river at an angle of about 15° . The following section shows this dip with the loess resting on the eroded surface.

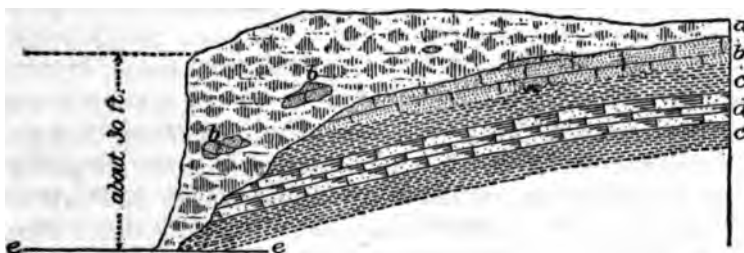


FIG. 1.—Section 5 miles south of Wichita.

a, loess; b, sandstone; c, shale; d, limestone; e e, level of river.

Northeast of Wichita a ravine and a cutting in the line of railway show Carboniferous shales and limestone covered by Tertiary formations, which is the only case of the kind yet recorded in this State. Near Winfield the Carboniferous limestones make valuable building stone, being in the massive ledges fine grained and entirely free from fossils. Thinner and more friable strata as well as shales, however, yield characteristic remains which, though rarely perfect, indicate the Carboniferous age of the formation. These are *Chonetes*, *Athyris*, *Hemipronites*, *Pecten* and *Productus*. On the ridge between the Walnut and the Arkansas the Carboniferous is mostly covered up by loess, and in the valley the alluvial sands are extensively deposited. From near Wellington westward, formations are extensively shown in thin ledges of limestone and thick shales which, while having some Permian (Carboniferous) resemblances, have also a different general appearance and a notable absence of fossils, giving them closer affinities with higher rock groups, as will appear further on.

The Carboniferous shale has been penetrated by well-borings to a depth of 180 feet. It is interbedded at intervals of from three to ten feet with hard ledges from two to six inches thick. It contains sulphate of lime, and the water from it is strongly impregnated. One of the hard ledges is of a peculiar shaly structure. It outcrops in ravines over an area of several miles. The slabs of it have a notable resemblance to a pan of biscuits fresh from the oven, only its surface is more regular in the smoothness of its domes. If a single dome be examined it is found hollow beneath. Both its surfaces are smooth, and it is thickest at the top of the dome. It will also separate into several thin concentric domes as would the layers of half an onion. Single layers of these have locally been taken for fossil shells. That this was a shore forma-

tion seems certain. Was the mud thus shaped by escaping gases modified by the action of the waves?

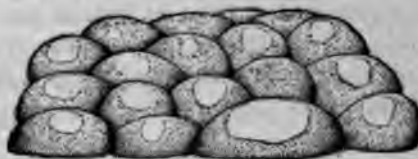


FIG. 2.—Bisenit shale (one-third natural size).

The heaviest Carboniferous shale is dark colored—the so-called “slate” of coal mines. Further west we find bands of buff and greenish clay-shales, and one, over a foot thick, of rich maroon color. On the west line of Sumner County the Carboniferous, or, as we shall see reason hereafter to call it, the Saliferous series disappears under the extensive sands of the Chikaskia, whose broad valley is a mere depression in the high prairie. This concealment by alluvial deposits is very extensive both south and north, so that the indication in the map of the western border of the Carboniferous development must be taken as only approximately correct.

Only incidental attention was given to the Carboniferous deposits, and no effort was made to ascertain their systematic relations. They are indeed only denominated Carboniferous by me in accordance with general usage.

JURA-TRIAS.

An extensive region, triangular in shape, whose northern apex is near the northern part of the Great Bend of the Arkansas River and whose base in Kansas runs on the southern boundary of the State from the ninety-eighth to beyond the one hundredth meridian, would be called by superficial observers the region of red rock. The area of the formation expands across the Indian Territory to the Red River and Texas.

This red rock, being overlain on some of its borders by dark brown and reddish ferruginous sandstones of the Dakota period, has been by many regarded as of Cretaceous age. It will be apparent, however, on a consideration of the facts which have been observed by me, that those geologists who have attributed the red rock to an earlier portion of the Mesozoic era are correct. In places these red rock strata present appearances which are similar to those which elsewhere have been called Permian. But though the relation of these to the uppermost Carboniferous (Saliferous) of their eastern border was not made out in the first reconnaissance, yet the stratigraphic differences of the beds themselves, as compared with deposits east of the Arkansas River, are on the whole so marked, that it is not possible for the writer to consider them as of Paleozoic age. On the other hand, in three places, at considerable distances from each other, strata of Dakota age were observed resting with erosive unconformity on the red rock series, which is the case with un-

doubted Permian strata in northern Kansas. The striking characteristics of the stratification of this formation, described later, appear to give sufficient reason, until paleontological considerations set it aside, for naming this formation the *Jura-Trias*, or it may be better to say only *Trias*. If a descriptive name were wanted we should call it the *Red Rock Formation*. The whole country is red. The soil, even where it contains much carbonaceous matter, is ruddy, the sedentary soil, just forming on the steeper slopes is ruddier, flooded rivers glance in the sunlight like streams of blood, steep bluffs and the sides of narrow cañons pain the eye with their sanguine glare.

Some buildings in the town of Harper are built of a brownish red-stone, which is obtained from quarries south and southeast of the city. Here and elsewhere the harder ledges are from two to eighteen inches thick, and they are intercalated with arenaceous clays and clay shales and clays of richer color. The hard ledges are persistent for long distances and give a definite contour to weathered bluffs and ridges. The clays are frequently of such toughness as to resist the weathering agencies as well as the harder ledges, which are sufficiently laminated and jointed to prevent their overhanging. Hence there are red walls by the streams, which are absolutely perpendicular. A specimen of one of the harder laminated layers from eastern Barber County, and a specimen of sedentary soil formed from that and adjacent ledges have been submitted to G. H. Failyer, professor of chemistry at the Kansas State Agricultural College, who says: "Both are strongly ferruginous, both rich in calcium carbonate. The stone is an impure limestone, containing ferric oxide, clay and sand. Of course the soil contains the two latter in excess." The ledges hard enough to supply building stone are comparatively rare. The thinner laminæ very frequently exhibit ripple-marks, raindrops and other signs of a littoral formation. Not unfrequently the upper surface of a lamina is brightly glazed, and at the foot of the bluff out of which a glazed specimen is taken may be found occasionally an illustration of the method of its formation in the glazed surface of dry red mud recently deposited from the overflow of a little stream washing the material both of the deposit and the glaze from the cliffs where it has so long been solidified.

The whole country increases in elevation westward and northward.¹ There is an undulation of the dip which is not often perceptible, with an average inclination westward of very small amount, while in some parts of the western half of the area there are local depressions southward as well as eastward. The elevation of the country combined with the average dip gives increasing thickness to the *Jura-Trias* as we proceed westward.

¹This is well illustrated by the fact, given by the engineers of the Southern Kansas Railway, that Medicine Lodge, in the deep trough of the Medicine River, is fifty feet higher than Harper, which is situated on the high prairie. The descent south-
erly from Medicine Lodge to New Kiowa is 150 feet.

It will be seen from the map that the Medicine River at Medicine Lodge turns suddenly southward. The reach of the river above that place gives a section from the Cretaceous formations above far down into the red rock. The lower reach of the river, to the State line and beyond, exhibits a section across the red rock. The eastern side is flanked by the Cedar Mountains or Hills, whose sides are scored by cañons not deep but narrow, with sides perpendicular, and with ridges and amphitheatres carved and pinnaced like oriental temples. West and south of the river are the Gypsum Hills.

The Gypsum Hills form the striking feature of the red rock country. Throughout the entire region the laminated arenaceous ferruginous limestone has in it globose spots of greenish white. This is apparently a fine sand. The spots, in many places regularly distributed and like small peas in size, sometimes aggregate into streaks. Occasionally the streak becomes a layer. One of these layers south and west of the Medicine River becomes persistent over a considerable area. The erosion of the valley has left this layer nearly at the top of the area in which it appears, which shows as an irregular plateau sloping east and north to the river. The layer is, in its outcrop, bleached and in places has the consistency of stone. We therefore call this the White Sandstone Plateau. This plateau is cut by deep cañons and its spurs occasionally terminate at the river as perpendicular red walls from twenty to thirty feet high. The upper reach of the river valley narrows westerly and the plateau narrows with it. The lower valley broadens southerly and the plateau increases with it. In neither direction is the plateau very wide. In the lower valley the western boundary of the White Sandstone Plateau is a solid wall of red rock, rising above it nearly two hundred feet, surmounted by a great white coping of gypsum from twelve to fifteen feet thick. The wall runs southward for several miles with some openings and terminates abruptly by a turn directly west. Northward its termination is a bold promontory, and the neck, with gypsum absent from it in places, is only wide enough on the top for one person to walk. From this point the wall retreats, forming a huge amphitheatre with isolated buttes and towers and caps, and all up the western valley towers, pinnacles and buttresses are repeated, advancing towards or retreating from the river. Approached nearer, the lights and shadows on the gypsum have the appearance of quaint gables and mansard roofs. Where the gypsum has disappeared single peaks are capped by projecting layers of the red rock. The butte I have called "Mansard" is within the amphitheatre on its western side. Some of these features are shown in Figures 3 and 4.

In ascending to the gypsum, we find that the red rock gives way frequently to seams of selenite and laminated layers of greenish sandstone. Again are found harder layers of the red rock, and anon seams of nearly transparent satin spar (fibrous gypsum), one of which is persistent for a great distance and two inches thick. These are in strata

or shale. Both the sandstone and satin spar layers are ripple . The top reached, we find all these pinnacles and buttes are remains of another plateau whose floor was this solid gypsum, stretches away to the south and west, broken by broad valleys found cañons, reappearing beyond the Cimarron, on the Canadian Red Rivers, and on the edges of the Llano Estacado. Views of this region of southern Kansas. Over the gypsum westward fragments of a hard gray limestone stratum, and again red rock. Gypsum has caves and underground channels, in which the sound and reverberates when horse or vehicle passes over.

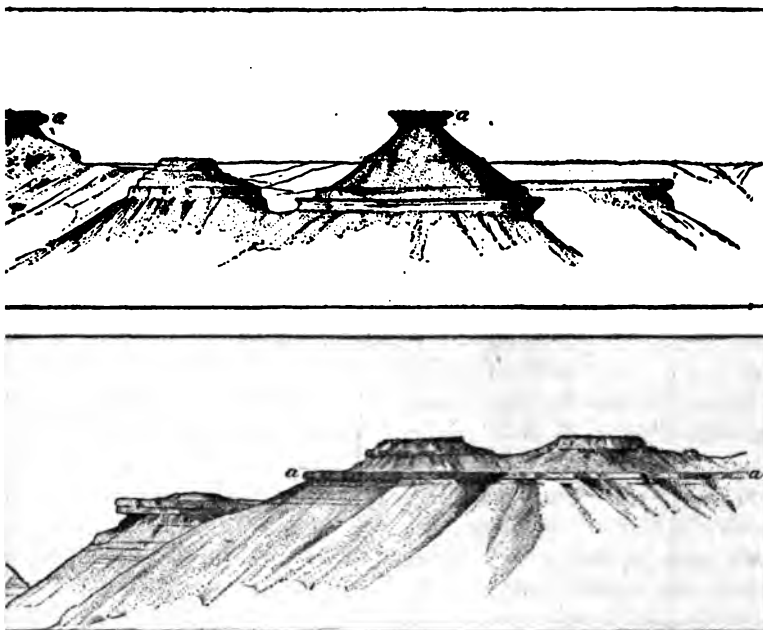


FIG. 3.—Red Rock buttes, Gypsum Hills.

or view represents the northeastern promontory of the Gypsum Hills. a, the gypsum cap.

er gypsum nor any of the red rocks or shales or clays have yielded any fossils. The constant evidence of littoral formation, however, suggests the expectation that sometime reptilian or corals may be found in this formation that will serve to synchronize with undoubted Mesozoic formations.

s in the valley of the Medicine are somewhat impregnated with lime. Some waters are also saline. But neither from the any of well sinkers nor from personal observation does it appear here is any seam of gypsum, satin spar or selenite below the top of the White Sandstone Plateau, except a little selenite in some in the town site of Medicine Lodge. Nor does it appear that any such seam above the horizon of the massive gypsum. It

ould therefore appear that there are three well-defined parts of the
ra-Trias in Barber County which may be possibly recognized else-

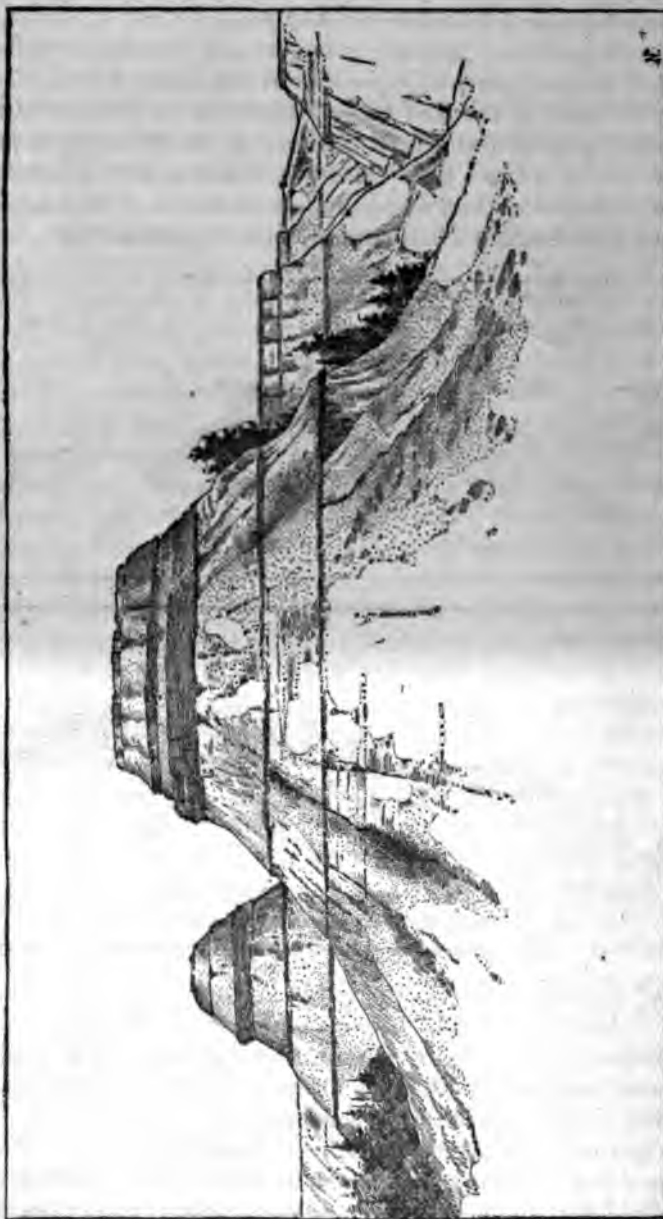


FIG. 4.—Mansard buttes, Gypsum Hills.

where. Only the lower one appears in Harper County. The thickness is given with hesitation. It may, however, be an approximation to the truth.

	Feet.
A. Upper red rock, above the gypsum plateau.....	100
B. Gypsum series, including the selenite seams and the massive gypsum.....	200
C. Lower red rock, from the White Sandstone Plateau downward (mostly without selenite seams).....	250
Total thickness.....	550

Several of the features described above suggest that the formation represents the Jura-Trias. These may be summarized as follows:

(a) The formation is lithologically quite distinct from the subjacent Carboniferous strata.

(b) The prevailing color of the formation is dark red, brown, and sometimes lighter red, like the Triassic generally in Europe and America.

(c) The lithified layers alternate with beds of clay and clay shale, as do the stony layers in the Triassic of the Atlantic slope and in much of the Jura-Trias of the West.

(d) A massive layer of gypsum and numerous seams of selenite and satin spar appear in the formation, in which respects it corresponds with deposits farther southwest, which have been referred to the Jurassic or Triassic on both petrographic and paleontologic grounds.

(e) There are frequent shore-marks, ripple-marks and rain-drops, in which the formation simulates the Triassic of the Atlantic slope and many other regions.

(f) There is a marked absence of fossils, a characteristic of the Triassic generally.

(g) The formation is continuous to Red River and appears to be stratigraphically connected with similar rocks beyond, which have already been referred to the Jurassic or Triassic on various grounds.

(h) The surface of the formation was deeply eroded before the deposits of the Dakota or other Cretaceous formations were laid down.

In brief, the lithologic characters, in so far as they may be regarded as criteria in the correlation of formations, and the stratigraphy alike suggest that the red rocks of southern Kansas represent the group of strata elsewhere found between the base of the Cretaceous and the summit of the Carboniferous; and although the evidence is not sufficient finally to demonstrate the age of the rocks, it is sufficient to warrant the provisional application to them of the name Triassic.

In 1887 the prospector's drill, boring for natural gas or coal, struck rock salt at Kingman, Ellsworth, Hutchinson, Lyons and Anthony, and in 1888 other places to the west of the more southerly of these made the same discovery. At an earlier date a boring at Wellington had given a similar result, but the thickness of only a few feet had not attracted the attention that the reports of hundreds of feet from the other borings did. A great industry has been rapidly developed. At all the places named, and at others, fresh water is put down the wells to the salt beds and comes up the pumps a saturated solution, from

which almost absolutely pure salt is extracted by the usual methods of evaporation.

The wells at Kingman and Anthony are in the red rock (Triassic) region, and the salt is obtained from strata *below* the red rock. The writer has visited all the localities named, and examination of the drill records showed that beneath the alluvia of the Arkansas Valley at Hutchinson and beneath Dakota formations at Lyons and Ellsworth the drill pierced several hundred feet of red rock, and as at Anthony and Kingman the salt was obtained below it. Early in 1888 I found outcrop of Triassic (red rock) strata in limited areas just south of the southern bend of the Smoky River in northern McPherson County. Borings east and west of Ellsworth showed the absence of red rock at Salina and Russell. It is thus apparent that the triangular form of the Triassic area, as shown in its surface development in southern Kansas, is prolonged northward under other deposits, and that Ellsworth is near the apex of the triangle. The strata with which the salt beds are associated, and which overlie them beneath the red beds, are mostly gray shales with some harder ledges. In a map and section illustrating a paper on the salt discoveries, read at the American Association for the Advancement of Science at Cleveland, in 1888, the writer has denominated these beds the saliferous horizon. The tendency of the evidence is to the effect that the strata of the saliferous horizon are continuous, without break, from the so-called Permo-Carboniferous beds which outcrop east of the Arkansas River. Further, these beds are continuous upward, without break, into the Triassic red beds. Thus we have a continuous series, absolutely unbroken, from Paleozoic into Mesozoic time. Recent investigations show that the shales and other exposures around Wellington belong to the saliferous horizon, and they, like the red beds, are absolutely without fossils. The deepening of a railway cut six miles west of Wellington shows there the superposition of red beds conformably on the upper gray shales, with a copper bearing horizon in the latter. This sequence is seen also at Caldwell. The results of these last observations would be to bring the eastern boundary of the Triassic red beds to the east side of the Chikaskia. A more extensive examination of outcrops of the saliferous horizon in Sumner County also confirms the writer's opinion, previously formed, that the saliferous beds, though probably continuous with the Permo-Carboniferous rocks below, have more affinities with the red beds above, and so justifies him in associating them at least provisionally with the Triassic series in estimating the total thickness, which in the southern part of the State from Anthony westward must exceed a thousand feet where not considerably eroded. The saliferous horizon differs from the red beds mainly in color, but it has what may properly be called a Mesozoic lithologic facies, difficult to describe but not difficult to understand by those who have worked in both Paleozoic and Mesozoic strata. The absence of fossils characterizes, as we have already seen, both the gray shales and the red beds. The gypsiferous horizon, which is a marked feature of

he highest beds of the Permo-Carboniferous period in northern and southern Kansas, may perhaps be taken as a premonition of the salt measures which succeed them in southern Kansas but which are altogether missing in northern Kansas. There the Dakota beds rest with erosive unconformity on the Upper Permian. Salt deposits in the Jimarron Valley, below the State line and the Meade County salt pool probably indicate another salt horizon above the Triassic gypsum.

In this report I have used the term Permian and also Permo-Carboniferous, for the highest Paleozoic beds, but do not intend to commit myself to the final use of the terms, which I will discuss elsewhere in connection with other investigations.

CRETACEOUS.

The formations referable to this epoch which came under observation in the reconnaissance, as provisionally identified, are in natural order:

- (1) The Niobrara.
- (2) The Fort Benton.
- (3) The Dakota.

THE DAKOTA.

Pebbles and nodules of the dark ferruginous sandstones of this formation are found in the gravels which overlie both the Trias and the Carboniferous, and these evidences of the existence of the parent beds increase westward, and among the red-rock bluffs north of Sharon a small patch of the Dakota was found in situ, manifestly deposited in an eroded hollow of the Trias. South of the town of Kingman, in the county of the same name, about half an acre of the ferruginous sandstone of the Dakota, that suggests volcanic action to the farmers of the Dakota regions, is similarly situate in a hollow of the red rock. Near the Barber and Comanche County line the same unconformity was observed, the Dakota being mostly composed of yellow, greenish, white and red sandstones. It also contains lignite, the reports of which warrant the belief that its beds are somewhat persistent. The brilliant coloring of these sandstones and their weathering into vertical cliffs and isolated "pulpit rocks" render the district one of remarkable variety both in color and in form. One stratum of darker ferruginous stain seemed identical with the nodule-yielding Dakota north of the Arkansas River, but we found no locality yielding the fossil leaves. The accompanying section (not drawn to scale) approximately represents the appearance in bluffs about six miles southwest from Sun City, and exhibits the changing conditions under which the lignite was found deposited. (See Fig. 5). The lignite itself is largely mixed with sand and has in it much pyrites.

THE FORT BENTON.

With reserve we are inclined to place the stratum called the "shell bed" in Fig. 5 in the Fort Benton group. A conspicuous feature of the lower part of the Fort Benton in northern Kansas is an extensive bed

of *Inoceramus* shells. It is from eighteen to twenty-four inches thick, is a white limestone, and can be traced just above Dakota sandstone a hundred miles. The shell bed of the diagram is of similar thickness, not so white, but also very extensive. Its shells, however, are not *Inoceramus* except to a very limited extent. They are almost entirely *Gryphæa*, mostly of the extremely variable form *G. pitcheri*, with an occasional *Exogyra*. We found a small patch of the bed in the hills north of Sharon, as well as farther south beyond the Barber and Comanche

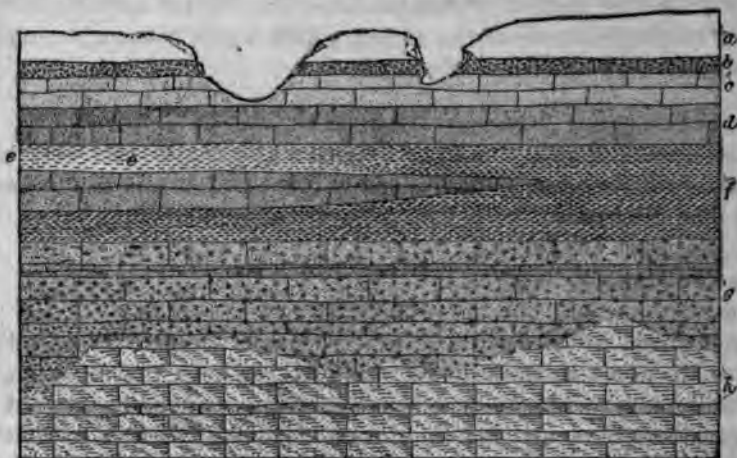


FIG. 5.—Section of Dakota strata resting on eroded surface of Jura-Trias.

a, slope of prairie; b, shell bed; c, yellow sandstone; d, red sandstone; e, shale; f, lignite; g, variegated sandstone; h, red rock (Jura-Trias).

line, and specimens of the shells were given to us from localities near the northwest corner of Barber County and the neighboring part of Edwards. The bed at the three localities where we observed it was composed almost entirely of small shells in a matrix of a limy conglomerate, the pebbles being very few, the shells making up three-fourths of the mass. We found them in all stages of preservation in the stream channels more than thirty miles from any development of the bed. We afterwards saw strata on Kiowa Creek (see Fig. 11) and on Spring Creek in Meade County (Fig. 6) which we refer also to



FIG. 6.—Section on Spring Creek, Meade County.

a, alluvium; b, Tertiary marl; c, Cretaceous.

the Fort Benton. Again, on the north of the Arkansas River, near the head of Saw Log Creek, there are shales and limestone (see Figs. 12

ed 13), whose fossils—*Inoceramus*, *Nautilus* and *Belemnites*—seem certainly to proclaim their Benton age. The line of contact between the Fort Benton and the Niobrara in northern Kansas has not been worked out, and in the region of this reconnaissance it is scarcely possible to do it at all, as the surface deposits cover the Cretaceous formations so extensively.

In connection with the statement that the shell beds (*Gryphæa*) of northwestern Barber County and neighboring districts were with reference attributed to the Benton epoch, it is interesting to know that in the same season in which the reconnaissance was made Prof. O. H. St. John made a hasty trip through this region and made some paleontologic collections of value. Besides reading so much of Professor St. John's results as were published in the Fifth Biennial Report of the State Board of Agriculture, I have had the advantage of personally comparing notes with him and going over his collections. It does not appear that Professor St. John examined the particular section shown in fig. 5, but the shell beds were seen by him in several places, and he says in the report just mentioned that they "are charged with fossils, mostly belonging to a species of *Gryphæa* resembling *G. pitcheri*, an *Exogyra*, *Trigonia*, *Turritella*, etc. The latter also occurs in the upper portion of the underlying shales. The association of species and abundance of individuals strongly recall occurrences in Texas. The *Gryphæa*, however, is noticeably somewhat larger, though otherwise very similar to the *G. pitcheri* prevalent in the latter region, offering in this respect specific differentiation, recalling that which to-day obtains with the common oyster passing northward along the Atlantic coast." (Fifth Bien. Rept. Kansas State Board of Agriculture, 1887, part II, p. 144.) These remarks relate to beds regarded by the observer as lying above Dakota sandstones, and recognized as different from the Dakota of northern Kansas, but not named Benton by him. He also hesitates to use the name Fort Benton for beds containing *Inoceramus* observed at no great distances from those described above, apparently on account of the absence of the northern Kansas bed of *Inoceramus*. He also says that these *Gryphæa* beds indicate the northern limits "of this peculiar southern fauna of the Cretaceous." I would observe that the specimens of *Gryphæa* seen by me in situ were all smaller than those collected by Prof. St. John and by others farther up the Medicine River than he went, and are exactly similar to specimens brought to him from Texas. Since the time of this reconnaissance Prof. Robt. T. Hill has located in Texas a lower Cretaceous series, to which has been given the name of the Comanche series, and the identity of the Barber County beds with the Comanche series has been suggested. If it existed it would apply not only to the shell beds, but to the sandstones below them, as they could not be Dakota if higher beds were a still lower Cretaceous. Before giving up the Dakota age of the sandstones (one bed in particular) I will have to reexamine the region, for it is certain the isolated patches at Sharon

and Kingman are Dakota. The sandstones in question are certainly unconformable with the red rock series. It is probable that the red rock series is Triassic; and it may be that the sandstones above are late Jurassic or early Dakota, and pass upward into Cretaceous shell beds without break, and are synchronous with beds elsewhere recognized as Dakota or even as Benton. The actual series of stratigraphic succession may possibly be worked out in the defiles of this region and the Indian Territory, but it will be a work of difficulty, as Tertiary and Quaternary deposits cover such large areas. If the stratigraphy be satisfactorily determined, it is possible that some paleontologic conclusions may have to be revised. In the shell beds referred to I obtained fossils that seemed without doubt to be casts of *Inocerami*.

Professor St. John found outcrops of Dakota sandstone near the Colorado line, and also of higher Cretaceous between the Cimarron and the Arkansas in the western counties; and he has since observed strata in northern Meade and southern Ford Counties, which he regards as Benton as certainly as those on Saw Log Creek north of the river, which they greatly resemble, though the characteristic shell bed of northern Kansas is missing. These localities, all small in area, have been indicated on the map illustrating the paper on the salt discoveries before referred to, which was read for me by Mr. W J McGee at the meeting of the American Association for the Advancement of Science at Cleveland, August, 1888. The estimate of their altitudes confirms the conclusions of the foregoing report on the easterly dip of the Cretaceous strata of western Kansas.

In Meade County there are indications of a sandstone horizon below the Benton which is probably Dakota. An artesian well in the Dakota formation on the west line of Clay County in northern Kansas, in connection with the easterly dip just mentioned led, me to suggest that artesian wells might also be made in southwestern Kansas that would yield water of fair quality at small depths. This has been verified on Crooked Creek, where numerous wells have a good flow of soft water from sandstones at depths of little over one hundred feet. These are nowhere on the high prairie, but are confined to the valley. They suffice for the irrigation of many farms. At Coolidge, in the Arkansas Valley, close to the Colorado line, the Dakota sandstones yield a limitless flow of water from an artesian well less than two hundred and fifty feet deep. Like that of other deep wells, this water is considerably mineralized.

THE NIOBRARA.

Rocks—shales and soft and hard limestones—of Cretaceous age are a conspicuous feature of the bluffs on the north side of the Arkansas River from Hartland west to the Colorado line. The yellow and white chalk and blue shale so characteristic of the Niobrara in the valleys of the Smoky Hill, Solomon and Prairie Dog Rivers are, however, not there. The fossils obtained were imperfect. *Ostrea congesta* was plen-

al in spots, and fragments of a large *Haploscapha* and *Scaphites*. Whether any part of this Cretaceous outcrop should be referred to formations above the Niobrara I will not undertake to say, as I believe will need much more stratigraphic investigation than I was able to give and some careful paleontologic work to determine the point. Meanwhile I assume provisionally that the exposures west of Hartland are of Niobrara age. The dip of the Niobrara strata in one place is found to be northerly, but generally all the Cretaceous rocks seen in the Arkansas valley had an easterly dip nearly corresponding with the general slope of the country.

In the sections (Pl. II, Figs. 2 and 3) the three Cretaceous formations are distinguished, but on the map they are indicated by one convention only. The full showing of all Cretaceous outcrops can be made only by a thorough study of the region.

THE POST-CRETACEOUS EROSION.

The main fact with regard to the Cretaceous formations brought out in this reconnaissance is that the Cretaceous surface was greatly eroded before the deposit of the Tertiary formations that follow. That this erosion was very extensive is evident. Its amount can not be easily determined, but that the result was a contour not very different from the present one in its main lines appears to be certain. There seems to be reason to suspect that the Laramie formation has some development in the northwesterly portion of Kansas, and possibly also in the extreme southwest. If this extended east, then the erosion was during the whole of Eocene time, or possibly longer. That the erosion was enormous is shown even by the facts observed in this reconnaissance. A full elucidation will require much longer time. The presentation of the facts observed in relation to the erosion of the Cretaceous strata will be best made in recording the observations on the Tertiary formations.

It is further to be observed that west of Dodge City the Cretaceous rocks have almost no surface development in the Arkansas Valley. The exposures west of Hartland are precipitous bluffs, mostly capped by the Tertiary formations. Occasionally these bluffs are terraciform, where the floor of one of the steps is a Cretaceous rock. Even the mere fringe indicated on the map is therefore an exaggeration if the scale be taken into account.

TERTIARY.

Two apparently distinct formations of Tertiary age have been found in all parts of the region explored. Occurring in isolated patches in the eastern part of the area, they are more largely developed as we proceed westward, where they are of such thickness and so related to the previous erosion as to completely hide other formations from view. Being sure of the identity of these formations with similar deposits in

northwestern Kansas, I am inclined to use the nomenclature of Professor Cope, and call these respectively the *Loup Fork* (Miocene) and the *Equus Beds* (Pliocene). But having regard to the extensive area over which the beds are developed and the comparative infrequency of fossils in the latter formation, I deem it best to designate them by purely provisional names and leave others to fix them more specifically when they have been examined over the whole region of the Great Plains and their subdivisions made out. These Tertiary formations then we name in ascending order: (a) *The Tertiary grit*; (b) *The Tertiary marl*.

THE TERTIARY GRIT.

The term grit is descriptive of this formation everywhere, yet it is of varying constitution. In places it encloses a fine powder, but the powder is largely siliceous, is useful as a polishing powder, and appears to be volcanic in its origin—wind-blown volcanic glass from the Tertiary centers of eruption in the west. Elsewhere the grit is an aggregation of sand and lime, which we call its mortar-like form. Again the lime exceeds the sand in quantity, and it is sufficiently fine to be used for inside plastering. Then we have the mortar form, enclosing abundant pebbles, quartz, feldspar, diorite, greenstone (hornblende), and more rarely granite with other igneous rocks. Then the limy matrix almost disappears, and we have a heavy conglomerate of water-worn pebbles of the rocks above mentioned, with jasper, quartzite and agate from the size of a nut to that of a large apple. Sometimes also there is a bone or a piece of completely silicified wood. The mortar-like form often hardens into a building stone, and its softer beds contain hard, tough nodules like indurated—not silicified—chalk. The conglomerate form changes at times into beds of a fair quality of sandstone. In some places it shows as a hardened bed of gravel, with well-marked cross-bedding. The mortar-like form is often a fossil bed, yielding bones of mastodon, *Aphelops* and turtle. There are in many places root-like concretions penetrating the softer forms of the grit, and where these softer forms are of considerable thickness—they attain in places a depth of fifteen to twenty feet—they are characterized by harder ledges at intervals of from two to three feet, which give very bold forms in weathering. The conglomerate is also manifested in abrupt breaks and rocky ledges.

Nearly all the foregoing characteristics of the grit were familiar to me in northwestern Kansas, so that there was no difficulty in identifying it in the region of this reconnaissance; but some of its occurrences were so far east that my note-book shows that I hesitated at first to recognize their identity. The increase of the area covered by the patches westward, and traces of remains of it in the form of thin gravel on slopes otherwise lacking signs of its presence, and its persistent occurrence as ledges a little below the highest prairie slopes, and, further still, its occurrence low in the river courses, indicated it as one of the

most extensive deposits of the western part of the State. I was further enabled to define more particularly two features of the grit which had been indefinite before: (a) In the Arkansas valley the conglomerate of the grit is mainly composed of pebbles of dark red feldspar. This is so marked a feature that its exposures, covered with the loose pebbles, can be recognized at long distances by their ruddy glow in the sun. In the valley of the Cimarron and in counties farther east the conglomerate is more often composed of quartz pebbles and pale feldspar, giving a whitish or grayish tint to the exposures. This will appear further in the discussion of Quaternary phenomena. (b) In several well marked instances I found the mortar form and the conglomerate together, indicating that they are not, as I had supposed, local variations of synchronous deposits. I found the mortar form below the conglomerate, the former having in those places its usual scant supply of pebbles. Rocky Point, a bold ledge of the conglomerate five miles west of Dodge City, gave this juxtaposition of the two forms, the mortar form showing only on the eastern or lower slope of the point and disappearing under the conglomerate. Elsewhere I found the mortar form embedding not only the pebbles of igneous rock, but also pebbles, both water-worn and angular, of the Cretaceous rocks of the region, these fragments being more or less silicified. A small patch of white sandstone, of which there were several near in Harper County (Sec. 5, T. 32, R. 5 west) had similar relation to the underlying red rock (Jura-Trias). The red rock, a nodular clay, shades upward into the sandstone, the intermediate part being a conglomerate of quartz pebbles in a pasty matrix of the red rock material. The sandstone itself has some pebbles of smaller size, and in the conglomerate the larger pebbles are below and the least amount of the coloring matter—the pasty matrix—above. The following sections show the positions of the sandstone and the red rock at this place:

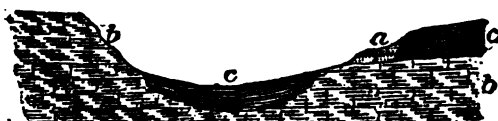


FIG. 7.—Section across a small ravine in Harper County.
a, sandstone; b, red rock (clay and nodules); c, alluvium.



FIG. 8.—Section down the east side of small ravine in Harper County.
a, sandstone; b, red rock (clay and nodules); c, alluvium.

The above sections show another fact, viz: the erosive unconformity of this Tertiary grit with the formation beneath. It is manifest that the grit was deposited in hollows of the eroded surface of the Triassic. Further, the depressions then were where there are depressions

now. This feature is seen in every exposure which shows the rock on which the grit rests. In places where the underlying rock is not seen it is observed to follow the slope of a side ravine toward the main valley, so that it is manifest that not only was the erosion extensive, but it was on nearly the same lines as that of to-day. The grit filled up the valleys to a considerable extent and was laid over the top of the higher land to a considerable height. Other illustrations I shall give when discussing the higher Tertiary formation. I give one other section (Fig. 9) which shows that these formations were laid in similar manner on Carboniferous (Permian) deposits. It is not far west of the ninety-seventh meridian, on the east of the Arkansas River, in a cutting of the Frisco road, three miles northeast of Wichita. The height shown is from eight to ten feet, and the length thirty to forty rods.



FIG. 9.—Section near Wichita.

a, Carboniferous limestone; b, Tertiary conglomerate; c, Tertiary marl; d, surface soil.

The illustrations of the post-Cretaceous but pre-Neocene erosion are so common, that almost every ravine has evidence of it in the Cretaceous district, and it is as common in the Jura-Trias region. Near the south line of the State, in the region a little west of the one hundredth meridian, several sections like the following could be seen at once in the banks of small streams.



FIG. 10.—Section in Meade County.

a, alluvium; b, Tertiary grit; c, Jura-Trias.

Similar sections may also be found in Barber County, both north and south of the Medicine River.

Fossils—fragments of turtle bones, as well as foot bones of *Aphelops* and some horse teeth—have been found in parts of Barber County. Horse teeth and some specimens of *Ostrea* (the latter apparently worn) were obtained from an exposure on Kiowa Creek. (See Fig. 11.) At the same place was obtained a fragment of a small mammalian jaw. A neighboring exposure also yields pretty specimens of *Lymnophya caperata*. Ampler exploration would undoubtedly reveal fossil deposits rivaling those of the bone beds of Phillips and Norton Counties, which yield remains of the larger mammalia by the ton. The fossils, with the exception of an occasional petrified fragment of bone or wood, are never found in the conglomerate. It is in the softer forms of the mortar grit that they abound.

The upper surface of the grit is much eroded. Its deposition was succeeded by a long period of subjection to sub-aerial agencies which

washed off a large part of its substance, rivers and smaller streams cutting it away nearly on the lines of the old valleys and nearly down to former levels. Then came another period of submersion and deposition, the material deposited making one of the most extensive and homogeneous formations of the Great Plains—the widely developed later Tertiary marl.

THE TERTIARY MARL.

Superficially this marl is not unlike the loess of the Missouri Valley, and in the middle of northern Kansas seems to shade into it, although in southern Kansas the loess is sufficiently distinct. The marl is arenaceous, argillaceous and calcareous in its texture. It is not at all like the mortar form of the Tertiary grit, except in a very few localities, where, owing to each having a predominance of sand, there is some difficulty in distinguishing them. Its color is very uniform. It is a buff marl everywhere. We saw no place where it was colored by the red rock of the Jura-Trias. It is buff on the yellow chalk of the northwest, on the Cretaceous limestones, on the Dakota sandstones, on the Jura-Trias, and on the Carboniferous strata. (See Fig. 9.) It contains chalky nodules irregular in shape, some root-like, resembling those in the Tertiary grit. Its texture is nearly the same everywhere. Where its bluffs are high its lateral exposures are wrought into rounded and symmetrical pillar-like forms, tapering to the top. Some views of it suggest the mauvaises terres of Nebraska.

In this reconnaissance evidence was found in two places of a subdivision of the marl into two deposits, the lower one in each case being more arenaceous than the upper one. (See Fig. 15.) The lower arenaceous stratum seems also to be indicated in wells where it yields the water after the marl has been pierced. But a later visit to the place figured showed considerable wearing in the face of the bluff and the sharp line no longer existed, but only a gradual increase downward of arenaceous structure.

We find the Tertiary marl resting on eroded surfaces of Permian, Jura-Trias, Cretaceous and Tertiary grit formations. It is sometimes low down, buttressing the flanks of other formations, but its best development is at the greatest elevations. It forms the dead level of the high prairie between the great rivers, thinning off towards their valleys, but following the slope of the tributary dales. This thickening on the high prairie is manifest in almost every county—Barber, Pratt, Edwards, Meade, Ford, Hamilton, Seward, Scott, Graham, Norton—from Indian Territory to the Nebraska line. Wells pierce it in most of these counties over one hundred feet, and in Meade County and in Graham from one hundred and forty to one hundred and eighty feet, before the grit is reached. The grit has a supply of water; the marl seems quite dry except in its lower stratum. Walls of dugouts and cisterns excavated in it may be plastered or cemented without the intervention of other material. The Buffalo grass is attached to the marl. *It remains on it after wire grass and others have taken posses-*

sion of sedentary soils of the grit or other formations. Where the sod has been broken by the plow, it has been found that the marl in a few years ceases to be so dry. It can then be broken by the spade, where before a pick was necessary.

The marl yields comparatively few fossils. Remains of bison and horse and other mammals have been found in it. It remains to be seen whether Cope's designation of the "Equus Beds" can be justified for so extensive a formation.

THE TERTIARY EROSION.

The greatest fact to which the Tertiary marl bears witness next to the one of the immensity of its own existence is that of the erosion immediately preceding its deposition. Assuming the grit to be Miocene, we may allude to this as the mid-Neocene erosion to distinguish it from the pre-Neocene erosion, which we have already described. The following diagrams give evidence of both periods of subaerial agencies. They are simply examples that might be multiplied almost indefinitely.



FIG. 11.—Section on Kiowa Creek, Comanche County, Kansas.

a, Tertiary marl; b, Tertiary grit; c, light drab and greenish shale; d, ledge of coarse yellowish sandstone; e, red iron ore.



FIG. 12.—Section across Saw Log Creek, north of Dodge City.

a, Tertiary marl; b, Tertiary grit; c, Fort Benton limestone; d, alluvium.

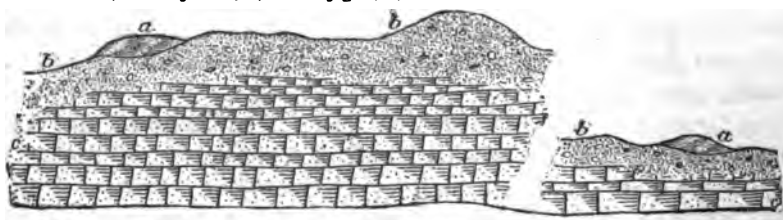


FIG. 13.—Section on south side of Saw Log Creek.

a, Tertiary marl; b, Tertiary grit; c, Fort Benton limestone.

For the sake of comparison I give the following from a "Report on the Geology of Norton County," made by me in 1884, to the Kansas Academy of Science. The locality of the section is in the Solomon Valley, south of Edmond, some distance east of the one hundredth meridian. The sections on Saw Log Creek are a little west of that meridian, but over one hundred miles south.

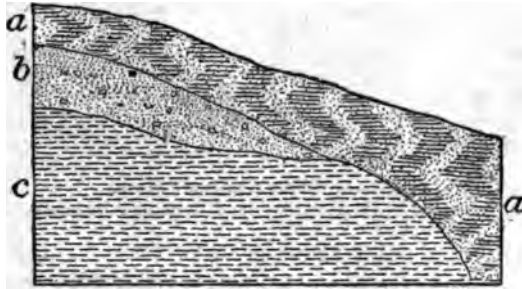


FIG. 14.—Section in Norton County, Kansas.
a, Tertiary marl; b, Tertiary grit; c, Cretaceous.

The following section of a bluff about 11 miles west of Dodge City shows in a striking manner the mid-Neocene erosion. The railway is on a terrace cut into the face of the bluff, and from the river up to this terrace the Tertiary grit is in place, and again it shows on the top of the next step; but the front of that step is formed of the Tertiary marl, which again appears back on the high prairie, thus showing an erosion-contour of the grit before deposition of the marl approximating to the form of the present valley. The line *s* in the diagram shows the position of the line of separation of the two forms of the marl already noted, the arenaceous character of the lower one being very marked (See p. 35, ante.)

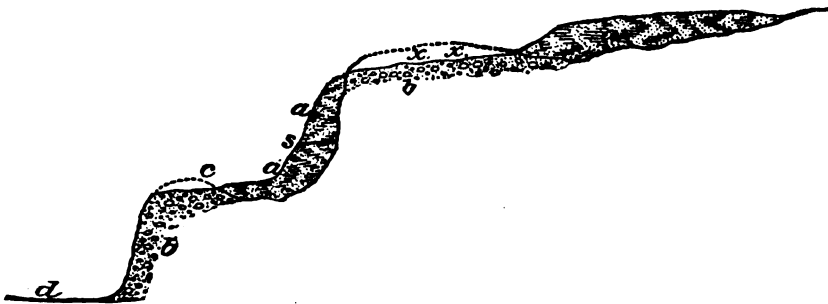


FIG. 15.—Tertiary bluffs on the Arkansas River.
a, Tertiary marl; b, Tertiary grit; c, railway terrace; d, river level; s, line of separation of the two forms of marl; x x, gravel of the conglomerate.

That the pre-Neocene erosion cut the valley of the Arkansas nearly to its present form is seen in the fact that small side ravines and other lateral valleys show the erosion of the Cretaceous rocks, with hollows partially filled with the Tertiary deposits. The following diagrams represent actual sections as seen from the main valley a few miles below Kendall.



FIG. 16.—Section in Hamilton County.
a, Tertiary marl; b, Tertiary grit; c, Cretaceous limestone.

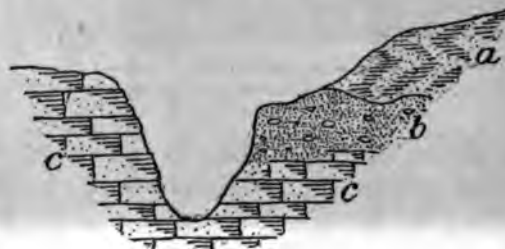


FIG. 17.—Section in Hamilton County.
a, Tertiary marl; b, Tertiary grit; c, Cretaceous limestone.

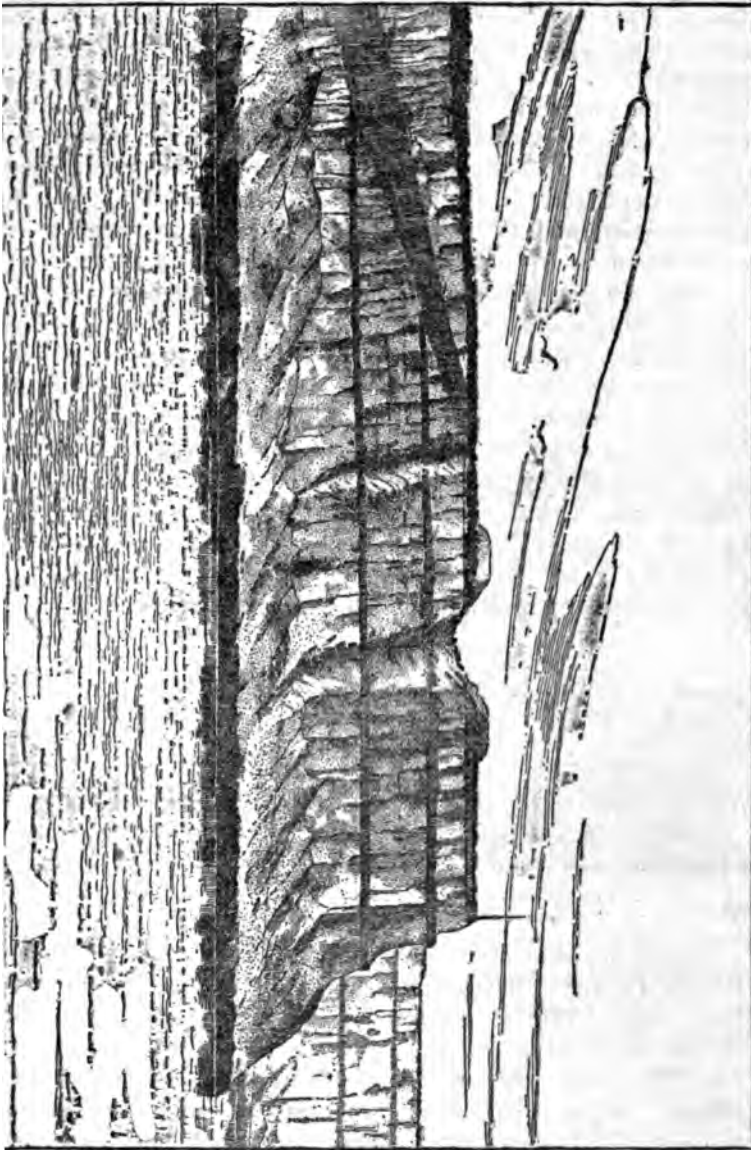
QUATERNARY.

The Quaternary deposits recognized in the reconnaissance are five in number. In ascending order they are: The Gumbo, The Earlier Gravel, The Loess, The Later Gravel, and the Alluvium.

THE GUMBO.

I take this name from a tough, solid, dark colored clay, which is so named in northeastern Kansas by the farmers, who dislike to find it near the surface. In my explorations I found it of a lavender color where weathered, but under the surface of a blackish brown. It is sticky and tough, but when dry breaks with a cuboidal fracture like hardpan. I found it in the Arkansas Valley forming the bottoms of pools, where the surrounding alluvium is almost pure sand. It occurs apparently beneath the gravel forming a good road-bed in Kingman County. In Clarke County I saw a few exposures of it in the faces of bluffs. The view at Red Bluff near the line of Clarke and Comanche Counties shows its occurrence overlying the Tertiary marl, and represents characteristic weathering of the red rock.

contact of the Gumbo and the Tertiary marl suggests intermission of the marl. More extensive exploration of Quaternary



ons will be required before such erosion can be positively af-

THE EARLIER GRAVEL.

mmense deposit of gravel lies under and around the town of ton, in Sumner County. It has been partially described in the City Review by J. P. West, and was by him referred to the

Champlain period. It has yielded fine teeth and jaws of *Elephas*, and also a fine skull and horns of *Bos latifrons*, which are now in the possession of Mr. John H. Wolfe, of Wellington. Water-worn fragments of petrified wood are found in it, and on the line of the railway to Honnewell, where the gravel is of finer material, it has yielded fragments of a large *Unio* and well preserved specimens of *Sphaerium sulcatum*. These fossils perhaps sufficiently determine the horizon of this deposit.

The gravel is composed of well worn pebbles, not very large but making the deposit in places notably coarse. The pebbles are mostly quartz and quartzite with feldspar and other igneous rocks, and an admixture of Permian cherts and limestone, granite being rare. Some of the mounds are quarried and the material is passed through sieves to obtain building sand. Besides the branch road to Honnewell, the Southern Kansas Railway also cuts the gravel, and the Atchison, Topeka and Santa Fé branch on the west side of the city gives a fine section of it. It is therefore possible to study the deposit pretty fully. It lies in eroded hollows of the saliferous strata, which can be traced over parts of the town site by the wells. Those which are in the gravel give good water; those in shale are strongly impregnated with gypsum. The relation of the gravel to the loess is distinctly shown, and is well illustrated in Fig. 19. The cross bedding in places is remarkable, evincing the presence of powerful and changing currents.



FIG. 19.—Section at cutting on Santa Fé Railway, Wellington, Kansas.
a, Loess; b, hard limy ledges; c, dark-colored shales; d, gravel.

Similar deposits of gravel are found occasionally to the west line of Barber County. Between Harper and Medicine Lodge they occupy large areas. They form the tops of the high prairie at Attica and east of that place for miles. They show depths of from five to twenty-five feet. The materials are the same as at Wellington, except the local material, which is in the western localities a reddish clayey extract of the red rock (Trias), which gives a sort of tenacity to the gravel and colors it distinctively. West of Attica the mounds are at lower levels. Medicine Lodge is on a mound which lies over a low spur of the red rock between Elm Creek and Medicine River. The railway cutting shows the contact of the gravel and the rock. Good specimens of teeth of *Elephas* have been taken from the gravel here and at Attica; fragments of large bones, shells, and fragments of the matrix containing them from the shell bed in Fig. 5 are also frequent in these gravels. North-

west and west of Medicine Lodge there are frequent mounds of gravel apparently synchronous with those already described, and northeasterly towards Kingman they cover large areas. The lower parts of the mounds are colored with the red rock, but the surfaces of the mounds are light colored, showing preponderance of quartz and buff feldspar pebbles. In western Barber County, and increasing west and north-west, there are other mounds of gravel not synchronous in their formation with those already described. I have designated them "the later gravel." I refer to them here because in western Barber County they are distinguishable from the gravel mounds under consideration only by careful exploration and not always with certainty then. The reason of this will appear further on.

Difficulties in arriving at precise results with regard to the Quaternary gravels lie in the fact of their immense area of distribution and in the large size of single deposits, combined with their position at the tops of the prairie. Currents of considerable force were required to move the material. It seems difficult in many cases to consider them river currents; more difficult still to consider them lake currents. A littoral current in the Irish Sea is, however, depositing just such gravel now. Further study is required.

The fragments of petrified wood in the gravel being mostly water-worn, they appear to be of greater age as petrifications than the deposit of the gravel. At least one silicified log seems, however, to be of wood of the gravel period. The log is of the color of the red rock.

THE LOESS.

The loess of the Missouri Valley is found as far up the Kaw Valley as the east line of Dickinson County. It extends up the Neosho to its source, but nowhere in northern Kansas does it appear to have passed much if any beyond the ninety-seventh meridian. At Wichita, however, it is strongly developed, and the water-shed between the Arkansas and the Walnut is mostly crowned by a heavy deposit of it. (See Fig. 1.) In the lower part of the Neosho Valley the loess is frequently much darker (orange brown) than in the Kaw, taking its color from the iron of various local deposits. But in the Arkansas Valley it becomes darker still, of a rich maroon. Farther west on the Minnesquah and the Medicine it becomes redder still. It is stained through and through, like the red rock, from which it is derived. In these valleys it attains its most westerly extension in Kansas. The comparative proximity of the Tertiary marl makes it easy to compare it with the loess. As compared with the later gravel, we have noticed that at Wellington the loess overlies the gravel; I infer a similar condition at Medicine Lodge, but I did not find the loess in any of the places (e. g., Attica), where the gravel is at relatively high levels. The bluffs of loess on the Medicine River show a characteristic that seems to have been inherited from the red clays of the Jura-Trias, i. e., they are more abrupt

in their contour than the Kaw River bluffs. The dry material has a cuboidal fracture, and the bluffs have a more precipitous appearance.

I have seen no fossils certainly referable to the loess of this district, but at Kiowa I was shown the humerus of a mastodon, which, from the stain and from its friability, I judged came from the red bluff formation. At Manhattan, in the Kaw Valley, the loess has yielded *Elephas*—teeth and tusks—at a depth of thirty-five feet.



FIG. 20.—Loess bluffs on Medicine River.

THE LATER GRAVEL.

A very conspicuous feature of the Arkansas Valley from Dodge City to the mountains is found in the frequent mounds of gravel. They stand out as rounded bluffs from the high lands that bound the main valley. Our specific description is from the occurrences within the state of Kansas.

Approaching one of these mounds, we find that very rarely does the gravel reach the bottom. There is frequently a well defined line, below which but few pebbles are found, and above which the gravel is plentiful. Again, there are mounds where the gravel does not reach the top. The top in such case is formed of the Tertiary marl. The pebbles, of which this gravel is largely composed, are of igneous rocks, hornblende, greenstone, granite (rare), quartz, quartzite, diorite, chalcedony and feldspar. The feldspar is mostly dark red, and it is so conspicuous by quantity as to give a ruddy tint to the whole surface of the mound. This ruddy tint can be distinguished at long distances in the sunlight. The pebbles vary from the size of a hand downwards.

I have elsewhere referred to the fact that pebbles of the same kind are scattered over the tops and at the bases of bluffs of the Tertiary conglomerate, and that such bluffs have the same ruddy tint. The fact is that the gravel mounds are simply the disintegrated conglomerate bluffs of the Tertiary grit. The bluffs and mounds are the two extremes of a series of great interest, every intervening term being found in the valley. We may state them thus:—

1. A beetling, craggy rock of conglomerate with a few loose pebbles.
2. A craggy ledge of conglomerate with a considerable talus of pebbles and sandy soil.
3. A flat ledge of conglomerate just showing above a sloping talus of gravel and a surface sprinkled with pebbles.
4. A rounded gravel mound.

The inner side of a mound (No. 4) sometimes shows its base of conglomerate not all gone but connecting it with a conglomerate ledge farther back.

The discovery of this series shows that these mounds are not, per se, transported gravels like the earlier gravels already described. As gravel, they are in situ and were produced by agencies at present in operation. Some of the mounds are thinly sprinkled with vegetation. Some have their structure almost hidden by a vegetable humus. There must be such mounds entirely buried by both alluvial and eolian deposits of sand, for traces of such are revealed by recent floods. The formation of such mounds, then, has been going on ever since the Tertiary conglomerate arose from the waters in which it was deposited, but the mounds which are now conspicuous I regard as of recent origin, synchronous with deposits which are called alluvial. Like alluvium, they are forming now and have been since the last upheaval from lake or sea. Hence the designation The Later Gravel. Many mounds in Comanche and Barber Counties belong to this later gravel, and possibly some in Kingman. They may be looked for wherever a fragment of Tertiary conglomerate is left. These more eastern mounds are of paler hue, like the conglomerate of which they are formed. The pebbles of quartz are more numerous and the feldspar is decidedly paler.

THE ALLUVIUM.

The alluvium of the region covered by this reconnaissance includes a class of deposits important because of their extent. The valleys of many of the streams are broad and comparatively shallow, giving large areas of both past and present flood plains.

A conspicuous feature of most of the river and creek bottoms is their arenaceous character. The immense beds of sand in the valleys of the Chikaskia, the Medicine, the Cimarron and the Arkansas are merely larger examples of what is shown in the bottoms of Elm Creek, Crooked Creek, Kiowa Creek, and numberless others whose beds in the dry season swallow up their streams entirely. The sources of this sand

are not far to seek. In the Jura-Trias region the decomposing red rock yields some sand. But the main source of all is the wearing away of the two Tertiary formations, both of which are rich in arenaceous material. So abundantly do they yield it that the quantity of sand in the eastern part of the region may be taken as evidence of their former existence in localities where they are not now observed. Where they do exist the ravines below their outcrop are mere sand beds.

Another characteristic of the arenaceous deposits is that they are sometimes found in places where they can not strictly be called alluvial. No river ever ran there. They have been formed in situ from the breaking up of the Tertiary marl by atmospheric agencies. Wind, rain and carbonic acid have broken and leached out the calcareous and argillaceous parts where the slope has not been sufficient to carry away the sand to any great extent, and the wind has helped to arrange the material as hills or low dunes both before and after the growth of vegetation. I regard the extensive sandy region east, southeast, and southwest of Coldwater as having been formed by agencies of this kind. It is an occasional feature of this region that at the base of a hill is a talus of the later gravel, and sometimes the sand all blown away leaves exposed a gravel mound or even a ledge of the Tertiary grit. These features are found in Barber, Ford and Hamilton counties, and probably to a much larger extent than our reconnaissance showed.

The sand dunes of the Arkansas Valley merit distinct notice. The entire river bottom is more or less arenaceous, but in places there is below a few feet of sand, or, at the surface, when the sand is blown or washed away, a deposit of stiff clay or gumbo. At Wichita this clay has been pierced for wells, and sand is found again at a considerable depth below. Farther up the broad valley, a little elevated above the level of the stream, is simply a sand bed, carpeted with the grasses of the region. From Cimarron west into Colorado, on the south side of the river and in places coming down to the edge of the channel, is a vast range of sand hills. Opposite Syracuse they attain a height of fifty feet, bare, glaring sand dunes, changing with the changing wind. Often, however, they are covered with some vegetation, and are assuming a more stable character. The tops of a large part of the range are from one hundred and fifty to two hundred feet above the river, and the range attains a breadth of six to eight miles. The sand brought down the river from Colorado is large in quantity, and its eolian distribution when the water is low is certainly extensive; but we can not regard the sand hills referred to as owing all their substance to the sands transported from the west. Their apparent height is not their real height as sand hills. They are buttressed against the sides of the valley, and passing through them southward we emerge, without diminution of altitude, on the prairie, whose level is formed by the Tertiary marl. On the river front of the dunes we occasionally find the red mounds of the later gravel, and pools within the hills have a bottom of gumbo. It appears certain, then, that much of the material of the dunes is of

strictly local origin, increased by the amount that the ever flowing stream may bring from the west. The sands absorb much of the rainfall, and what should be water courses are mere sand beds. Bear Creek in wet weather is a series of pools, but it never reaches the river as a surface stream. Two of the pools are what are known as "sunk wells;" one of them is said to show no bottom at two hundred and forty feet, and the other is over one hundred and fifty feet in depth. It is certain that alluvial deposits are very deep in the Arkansas Valley. It is possible that the depth of these sunk wells represents the depth to which the ravines and, approximately, the main valley were excavated by Eocene or mid-Neocene erosion.

The Arkansas Valley has also an argillaceous alluvium. This is found in places as much as 50 feet above the present level of the river. At Hartland and below Cimarron ledges of rock approach the river from both sides. These are probably the remains of barriers which existed before the river was reduced to its present base level, and above which alluvium may have been deposited in exceptional quantity, but the period of the excavation of the short gorges between the barriers is unknown.

The alluvial deposits of the Medicine and tributary valleys claim a passing notice. I have referred to those of an arenaceous character. There are others decidedly argillaceous. These are red. They are finer grained than the red loess of the valley. The loess is finer grained than the red rock clay of which it is mainly formed. It would be interesting to examine these three forms with respect to the physical and chemical conditions of their materials and their relation to the fertility of the soil. The red rock soils—both sedentary and transported—are fertile.

CONCLUSION.

THE GENERAL RESULTS.

Among the results of this reconnaissance has been the distinct recognition of various formations in the region explored. It is not to be expected that a hurried reconnaissance should enable the geologist to delineate the formation boundaries of a considerable area with much exactness; and accordingly the boundaries indicated on the accompanying map are to be regarded as provisional, excepting in the immediate vicinity of the route traversed. The determination of the great westerly and southerly extension of the two Tertiary formations is an addition to American geology; the discrimination of the two Quaternary gravel deposits is believed to be new; and the tracing of both gravel beds to their sources in the Tertiary conglomerates is of local and general value as a means of ascertaining the origin of certain superficial deposits.

The Source of the Tertiary Conglomerates.—One of the most interesting problems suggested by the reconnaissance relates to the origin of the materials, particularly the coarse gravels, composing the Tertiary

formations. It has, indeed, already been inferred by geologists familiar with the region that the materials of the Tertiary conglomerates were originally derived from the Rocky Mountains; but investigations of the reconnaissance confirmed by more recent explorations have placed the inferences on a firmer basis than ever before. There is a series of mounds of gravel and of conglomeratic deposits along the western margin of the Great Plains in Colorado, well exhibited from north of Denver to below Pueblo; these deposits are apparently the westward continuation of the Tertiary grit of Kansas, and their materials are so similar to those of the deltas and alluvial fans built by the mountain streams at the mouths of their cañons as to prove identity of source. It is true that in the Tertiary grit of Kansas, the physical condition of the materials and the proportion of the various elements are different from those found in the gravel mounds, conglomerates and alluvial fans at the immediate base of the mountains; the materials are universally finer and better rounded, and there is a predominance of quartz and other obdurate minerals; but the differences in the coarseness and in the mineralogic character of the materials observed between the ninety-eighth meridian and the Colorado boundary are even greater than those occurring between the Colorado boundary and the Rockies.

It is probable that the Wichita Mountains of Indian Territory, which are composed of igneous rocks, have contributed material for the Tertiary formations of Kansas; but the character of the pebbles and the direction of the mountains with respect to slopes alike indicate that this source was unimportant.

The manner of transportation of pebbles so coarse as those found in the Tertiary conglomerate in southwestern Kansas over the four hundred miles intervening between the localities described above and their original source, remains a problem. The Tertiary deposits were laid down in lakes or inland seas in which the currents could have been of but limited strength—probably too limited to permit of transportation of such coarse materials. It may be suggested that the period of deposition of the Tertiary grit of western Kansas and eastern Colorado witnessed the progressive elevation of the Rocky Mountains either by steady uplift like the coast of Sweden, or by a succession of sudden upheavals like the Andes, and that during this period the shore of the lake with its attendant shingle and littoral debris and the mouths of the mountain-fed affluents from which the debris was derived, were progressively shifted farther and farther to the eastward, and that the coarser and finer phases of the Tertiary conglomerates throughout the whole area thus represent successive littoral deposits.

The Question of Tertiary Shores.—A second problem suggested by the reconnaissance relates to the eastern shores of the water bodies in which the Tertiary deposits were laid down. Little progress has been made in the solution of this problem. No unmistakable Tertiary deposits were found as far eastward as the ninety-sev-

dian either in situ or in the form of residuary sands and gravels, and there is nothing in the topography or in the behavior of the rivers to suggest that the formations ever extended much farther eastward. It is significant, however, that the course of the Arkansas River is suddenly changed above Wichita, and that a prominent ridge—the Flint Hills—which attains an elevation of sixteen hundred feet and which might have formed a barrier for the Tertiary sea, occurs just eastward. It is possible that evidence of the coincidence of the old shore with this ridge may ultimately be found, but such evidence has not thus far been brought to light.

The Tripartite Erosion.—The most striking facts developed by the investigation of the Great Plains are connected with the three periods of erosion. The profound depths of the Grand Cañon of the Colorado give a visible exhibition of erosion, that from the direct evidence of the senses affects the imagination of even the illiterate. But on the plains it is only after painstaking observation, during a long time and over extended area, that the great fact of the erosion is made out. But when it is made out, and the mind grasps it, it is as striking a fact as the Colorado chasm. Here is an area whose dimensions are not less than the whole State of Colorado, which has been cut first into great valleys—from the Platte to the Canadian—and its general level lowered several hundred feet after the close of the Cretaceous period. Next it was submerged, and a deposit, the Tertiary grit, laid over it to a depth

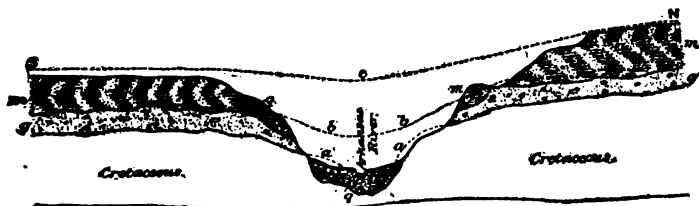


FIG. 21.—Section across the Arkansas Valley.

m, Tertiary marl; g, Tertiary grit; c, contour at commencement of post-Tertiary erosion; q, Quaternary deposits; a, assumed contour at close of pre-Neocene erosion; b, assumed contour at commencement of mid-Neocene erosion.

of probably fifty feet. Then after emergence so uniform that the new waterways followed the old, it was again eroded, the grit almost entirely disappearing in the valleys, and being certainly much thinned elsewhere. Another submergence spread over all the area a deposit which on the highest points is yet two hundred feet thick, and must have been thicker in the valleys. And this has again been eroded, generally along the old lines, and cut down to and below the depth of the first cutting into the Cretaceous rocks. The mean total erosion for the whole region can not be less than three hundred feet, as it must much exceed that in the valleys.

The generalized section in Fig. 21 shows the observed facts of the Arkansas Valley, commencing with the close of the pre-Neocene erosion. The broken line *a* shows an approximation to the eroded surface of the Cretaceous strata at the commencement of the deposition of the grit. The line *b* represents the completion of the grit. The line *c* may be taken

as the probable level at the post-Tertiary emergence of the marl. At present there are no data for estimating the original height of the Cretaceous strata. Sections like this, differing only in detail, can be constructed for the Smoky Hill River, the Saline, the Solomon, the Prairie Dog, and the Sappa, and, in smaller areas, the valley of the Cimarron. The Tertiary grit forms in parts of Seward county the bed of that stream.

The average dip of the strata in the region of Carboniferous formations is to the west; the dip of the higher Cretaceous rocks in the Arkansas Valley is certainly towards the east. Both northerly and southerly local dips have been noticed. It has not been easy to decide how to represent the observed facts, but in the sections forming Pl. II the dip is believed to be approximately correct.

These varied phenomena of the plains, then, are all the results of this complex application of the force called erosion. Its manifestation is on every hand. It has carved the weird forms and the deep cañons of the Gypsum Hills. It has cut out the broad valleys of the great rivers and the narrow ravines of the torrents. It has spread out vast sheets of sand and piled up mounds of gravel which it has brought from higher regions, and it is, day by day and year by year, still degrading the solid rock and sapping away the solid body of the high prairies of the west.

ECONOMIC GEOLOGY.

It is not possible to give proper discussion here to the facts of economic value in this region, mainly because they could not have the investigation their importance warranted. They have been incidentally touched in preceding pages, and here I will note only that observations on the water-holding capacity of the Tertiary grit have been published by me in a bulletin of the State Board of Agriculture, and, being extensively copied in the newspapers, have been useful to the settlers of the Southwest. Similar observations were also made by Professor St. John. It is interesting to note that recent examinations in northern Kansas have revealed traces of the Tertiary formations east of the ninety-seventh meridian.

The gypsum deposits are being practically utilized in the manufacture of stucco and plaster-of-Paris, and some beds yield marble and alabaster that may take a place in ornamental architecture. Some of the red beds at Kingman are yielding a fine quality of mineral paint. The Cretaceous formations are in places yielding building stones that are of great value to the increasing population of southwestern Kansas.

The salt rock on the confines of the Permian and Triassic formations is of great thickness and is being extensively utilized at Hutchinson and elsewhere. At Kingman it has been reached by a shaft which has already passed through 24 feet of solid salt in four layers, and thicker veins are expected at a somewhat greater depth than that now reached (700 feet).

INDEX.

	Page.		Page.
of Kansas.....	43-45	Mississippi Valley and Rocky Mountain	
River, Tertiary bluffs on.....	37	region, contrast of geologic history ..	12
Valley, sand dunes of.....	44-45	Missouri Pacific Railway, aid by	9
on across, showing repeated ero-		Mudge, B. F., cited.....	16
a.....	47	Acknowledgments to	18
wells.....	13, 30, 48	Niobrara formation of Kansas.....	30, 31
Topeka and Santa Fé railway,		Norton County, Kans., section in	37
by.....	9	Paleozoic history of the Mississippi Valley.	11, 12
hale.....	19, 20	Petit Anse Island, La., salt deposits at	13
F. H., cited.....	17	Quaternary deposits of Kansas.....	38-45
lignites in the Great Plains, ques-		Red beds, economic value of	48
ns concerning	13	Red bluff, Kans., exposure at.....	38, 39
strata, Tertiary, source of	45	Red rocks of Kansas	14
D., cited.....	16	Red rock, region of.....	20-26
strata of southwestern Kan-		Rocky Mountain and Mississippi Valley	
.....	19, 20	geology, discrepancy between	12
ns formations	16, 27-31	Rocky Point, Kans., exposures at.....	33
formation	16, 27	St. John, O. H., acknowledgments to	18
H., determinations of fossils by ..	9	Cited	29, 30
ity, Kans., exposures near	33, 37	Saltiferous horizon, extent and geologic	
o geology.....	48	place of.....	26-27
sds.....	36	Salt deposits of Petit Anse Island, Louis-	
of the Great Plains.....	47	iana, and elsewhere	13
G. H., cited on chemical composi-		Salt rock, utilization of	48
n of Kansas rock and soil.....	21	Salt wells of Kansas	25, 26
ton formation	27-30	Sand dunes of the Arkansas Valley.....	44, 45
" railroad, aid by	9	Satin spar	22, 23
formations of southwestern Kansas		Saw Log Creek, exposures on.....	28, 29, 36
The Earlier) of Kansas.....	39-41	Sharon, Kans., exposure of Dakota forma-	
The Later) of Kansas	41, 42-43	tion at	27
beds of Kansas, significance of...	29	Shores, Tertiary	46, 47
The) of Kansas	38, 39	Shumard, G. C., cited	17
deposits, economic value of	48	Simmons, J. H., aid by.....	9
, location and structure of.....	22-24	Southern Kansas Railway, aid by.....	9
n County, sections in	38	Spring Creek, Kans., exposures of Fort	
County, sections in	33	Benton formation at.....	28
ert T., cited.....	29	Superficial deposits, review of	12
as in Kansas	20-27	Swallow, G. C., cited	17
Kans., sections seen near	38	Tertiary grit.....	32-35
a, Kans., exposures of the Dakota		Tertiary formations of Kansas.....	31-38
mation at	27	Tertiary marl.....	35-36
rock, Kans., exposures on	28, 34, 36	Tertiary conglomerates, source of.....	45
Kansas	41, 42	Tertiary shores in Kansas	46-47
rk formation	16	Triassic rocks, review of.....	12, 25
ds of	18	Triassic red beds of Kansas, boundaries of.	26
W. J., acknowledgments to	9	Wellington, Kans., deposit of gravel at	39
R., aid by.....	9	Wells, Artesian.....	13, 30, 48
ounty, section in	34	West, J. P., described gravel deposits at	
River, alluvial deposits of.....	45	Wellington, Kans.....	39-40
history of western Mississippi		White Sandstone Plateau	22
lley.....	11, 12	White, C. A., determination of fossils by...	9
rpi Valley, summary of geologic		Wichita, Kans., exposures near.....	17, 19, 34
tory of.....	11, 12	Deposits of loess at	41

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 58



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



1000

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

THE
GLACIAL BOUNDARY

IN

WESTERN PENNSYLVANIA, OHIO, KENTUCKY,
INDIANA, AND ILLINOIS

BY

GEORGE FREDERICK WRIGHT

WITH AN INTRODUCTION BY THOMAS CHROWDER CHAMBERLIN



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



1

CONTENTS.

	Page.
of transmittal.....	11
DUCTION BY T. C. CHAMBERLIN.....	13
ces of the upper Ohio River district.....	22
he high horizontal terraces.....	22
he higher river terraces.....	24
he lower river or moraine-headed terraces.....	32
General remarks on the two systems.....	33
he slender horizontal terraces.....	37
he structural terraces.....	38
ation.....	38
GLACIAL BOUNDARY IN WESTERN PENNSYLVANIA, OHIO, KENTUCKY, IN-	
NA, AND ILLINOIS, BY G. F. WRIGHT.....	39
duction.....	39
ted surfaces of rocks in place.....	39
nary of facts concerning the unstratified deposit called "till".....	42
reliminary remarks.....	42
eneral distribution of till and its relations to buried channels.....	43
haracter of the material composing the till.....	45
ource of boulders in the till.....	50
larity of distribution of till near the margin.....	52
Distribution of the till east of the Alleghanies.....	52
New England.....	52
New Jersey.....	55
Pennsylvania.....	55
Northampton County.....	55
Monroe County.....	55
Luzerne County.....	56
Columbia County.....	56
Lycoming County.....	56
New York.....	56
Cattaraugus County.....	56
Distribution of the till west of the Alleghanies.....	57
General remarks.....	57
Pennsylvania.....	58
Warren County.....	58
Venango County.....	59
Crawford County.....	59
Mercer County.....	59
Butler County.....	59
Lawrence County.....	59
Beaver County.....	59

CONTENTS

	Page
regularity of distribution of till near the margin—Continued.	
Distribution of the till west of the Alleghanies—Continued.	
Ohio.....	59
Columbiana County.....	59
Stark County.....	60
Holmes County.....	60
Knox County.....	60
Licking County.....	61
Perry County.....	61
Fairfield County.....	61
Ross County.....	61
Highland County.....	61
Brown and Clermont Counties.....	61
Hamilton County.....	62
Butler County.....	63
Kentucky.....	63
Campbell County.....	63
Kenton County.....	63
Boone County.....	64
Trimble County.....	65
Indiana.....	65
Dearborn County.....	65
Ohio County.....	66
Switzerland County.....	66
Jefferson County.....	66
Ripley County.....	66
Jennings County.....	67
Clarke County.....	67
Scott County.....	67
Jackson County.....	67
Bartholomew County.....	67
Decatur County.....	68
Johnson County.....	68
Brown County.....	68
Monroe County.....	68
Morgan County.....	68
Putnam County.....	69
Owen County.....	69
Greene County.....	69
Sullivan County.....	69
Knox County.....	69
Davies County.....	69
Gibson County.....	69
Vanderburgh County.....	70
Posey County.....	70
Illinois.....	70
White County.....	70
Gallatin County.....	70
Saline County.....	71
Williamson County.....	71
Jackson County.....	71
Randolph County.....	72
Missouri.....	72
Jefferson County.....	72
St. Louis County.....	72
General remarks.....	

CONTENTS.

7

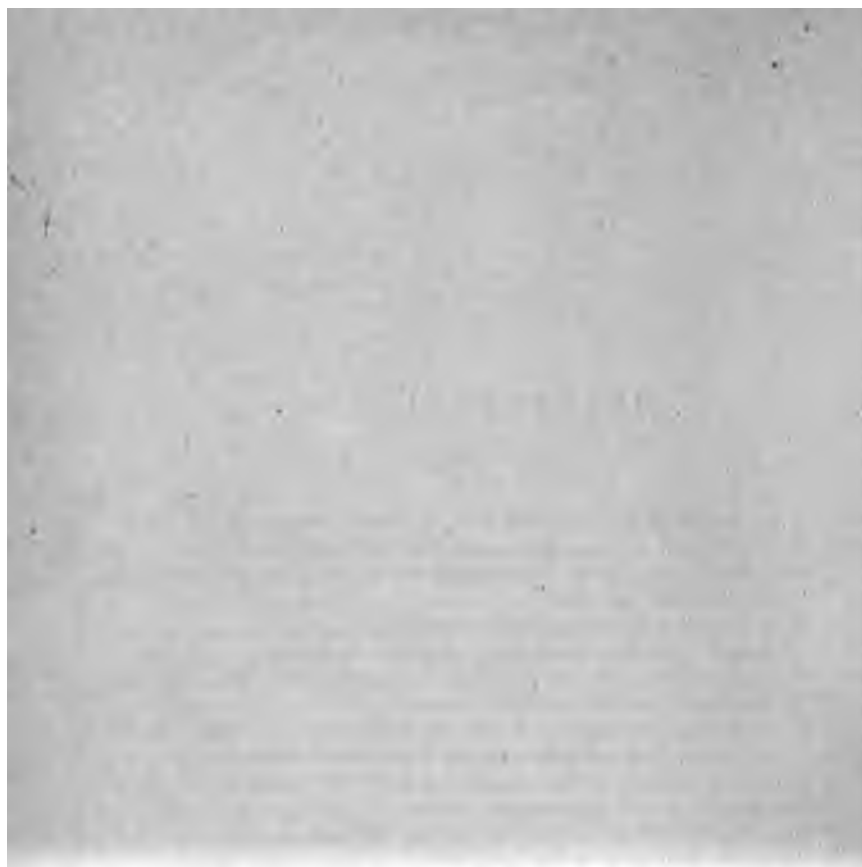
	Page.
hypothesis of a glacial dam at Cincinnati	76
Introduction	76
The lower terraces of the Ohio and its tributaries	76
The upper terraces of the Ohio and its tributaries	80
Theoretical explanations	82
The upper terraces the remnants of a distinct glacial epoch earlier than that producing the lower	82
Facts adverse to this theory	83
Terraces on the Monongahela	83
River deposits in Teazes Valley, West Virginia	86
Terraces on the Big Sandy	88
Terraces on the Elk River	88
Terraces in Bath County, Ky.	90
Beech Flats, Pike County, Ohio	92
Freshness of the vegetable remains near the glacial margin	96
Summary	100
Glaciation and its relation to the glacial drift	101
near the glacial margin	104
glacial man in Ohio	105
final conclusions	108



1

ILLUSTRATIONS.

	Page.
I. Section of till at Lane's Mill, near Darrrtown, Butler County, Ohio..	48
II. Exposure of till some miles east of section shown in Plate I	50
III. Cliff of post-glacial conglomerate south of Woolper Creek, near Split Rock, Ky	64
IV. A near view of cliff shown in Plate III	66
V. Map of southern Illinois showing glacial boundary	70
VI. Section of deposit near Hurricane, in Teazes Valley, West Virginia.	88
VII. Section of peat and drift, Germantown, Ohio	96
VIII. Section of till showing wood, one mile south of Oxford, Butler County, Ohio (on a tributary of Four-mile Creek)	98
1. Striae on the summit of the Alleghanies, Sullivan County, Pa	40
2. Map showing glacial boundary in Ohio	46
3. Map of southern Indiana showing glacial boundary	65
4. Map of the tributaries of the upper Ohio	77
5. Map of the old channel of the Monongahela, between Masontown and Carmichaels, Va	86
6. Map of Teazes Valley, West Virginia	87
7. Outline map of Elk River, West Virginia	89
8. Map showing terrace at Bellevue, Pa., and the relation of Chartier Creek to the Alleghany River	91
9. Map showing the still-water deposit between Paint Creek and Brush Creek, southern Ohio	92
10. Map of Hamilton County, Ohio, showing situation of glacial terrace in which paleolith was found.	106



1

1

LETTER OF TRANSMITTAL

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF GLACIAL GEOLOGY,
Washington, D. C., May 23, 1889.

SIR: I have the honor to transmit herewith for publication as a bulletin of the Survey a paper prepared by Prof. G. Frederick Wright on the glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, to which I have prefixed an introduction reviewing certain questions of wide interest and debatable interpretation.

Very respectfully,

T. C. CHAMBERLIN,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.



INTRODUCTION.

BY T. C. CHAMBERLIN.

The following paper is one of a series of important contributions toacial geology, issued under different auspices, whose objects are to set forth the extent of the northern ice-borne drift with greater precision and detail than have been before practicable. In a general sense, the extent of the drift of the Atlantic border region and of the interior has long been known, but more or less lack of precision respecting its limits and marginal character has prevailed. In the western part of our territory definite knowledge has been much more limited and misconceptions of some gravity have obtained. No other state of knowledge was to be expected in view of the vast stretch of territory involved and the multiplicity of broad questions forced upon the attention of the earlier geological surveys, whose functions were rather to determine the chief features of a score of diverse formations than to trace out into complete detail any selected one. But about a decade ago (1876) a movement in the direction of more careful delineation of the outer margin of the drift was initiated by Profs. George H. Cook and John C. Smock, of the New Jersey Survey, and this was followed, at short intervals, by similar work on the southern border of New England by Warren Upham and other volunteers; across Pennsylvania by Profs. H. C. Lewis and G. F. Wright, under the auspices of the Geological Survey of that State; and across Ohio and Indiana by Prof. Wright, through the aid of the Western Reserve Historical Society. The present bulletin includes the extension of this work of delimitation to the Mississippi river, under the auspices of the U. S. Geological Survey. West of the Mississippi considerable progress has been made by Profs. R. D. Salisbury, J. E. Todd, and myself in delimiting the northern drift and determining the character of its border, but the details yet await publication. In the main the consecutive tracing of the border of the drift has not been attempted in that region, but determinations have been made at frequent intervals along the margin in connection with other work, deemed, at the present stage, more important.

All those who have been engaged in these recent and more careful studies of the border of the drift, though they have come to the study from different associations and under different auspices, have given

assent in greater or less measure to the doctrine of the glacial origin of the drift, and have employed its working hypotheses. All are not, however, equally exclusive in their employment of these hypotheses. At present a portion of the investigators incline to the view that all the marginal deposits, save, obviously, the water-washed gravels, sands, and clays, are of direct glacial deposition, while others are undecided respecting *certain portions*, doubting whether they were deposited directly by land ice or indirectly by floating ice in bodies of water marginal to the great ice field.

There are also important differences of view respecting the unity of the marginal deposits and the continuity of the history of glaciation. Some of the investigators appear to give adhesion to the belief that the entire margin was produced at practically the same time and by the same great field of ice, while others entertain the confident belief that different portions of the margin were produced at different times and by independent ice invasions, or, at least, ice advances. These divergences of belief and these withholdings of belief constitute a wholesome intellectual environment which it is not desirable should be replaced by complete unity of interpretation until such unity shall be compelled by the force of evidence. It is essential, however, to its wholesomeness that the fact and the nature of the divergences should be distinctly understood wherever confusion or misapprehension are liable to be introduced into the literature of the subject, and wherever the general reader, who has not traced critically the growth of opinion, may otherwise be misled.

Certain of these divergences of view and certain more specific differences of opinion, to which attention will presently be called, exist between the author of this paper and myself, in view of which Prof. Wright in transmitting this paper indicated that it would cause him no surprise if I should express dissent from some of the views advocated in this bulletin. It seems to me consonant, therefore, with a full appreciation of the obviously great value of the data here presented, to call attention to certain points of divergent interpretation.

The first difference of opinion springs from the marked diversities which the character of the drift border presents.¹ In the Atlantic and Appalachian regions the margin is generally marked by ridged accumulations, bearing the specific characters of a terminal moraine, whereas in the Mississippi Valley and on the plains west of it the drift ends in a thin margin, unmarked by specific terminal ridging. The bordering

¹The diverse characters of the drift margin appear to have been first clearly distinguished on the border of the driftless region of the Upper Mississippi, and were specifically discussed by my associate, Prof. R. D. Salisbury, before the Wisconsin Academy of Science in 1884, who set forth the contrasted facts that along certain stretches the margin consists of thick-ridged accumulations, constituting definite terminal moraines, while along other stretches the drift ends in attenuated edges. The subject is more fully brought out in our joint paper on the driftless area of the upper Mississippi Valley, in the Sixth Annual Report of the U. S. Geological Survey.

moraine at the east departs from the extreme limit of drift, according to our present knowledge, as I interpret it, in western Pennsylvania. There the outermost moraine¹ lies a few miles back from the limit of drift, the extreme edge being formed of thinly dispersed erratics. Westward from this there is a wider departure of the two, and in the immediate valley of the Mississippi the terminal moraines thus far identified lie remote from the border. I have elsewhere assigned reasons for believing that these are the essential equivalents of the ridges which lie along the border in the Atlantic region. However this may be, I entertain the view that the drift sheets of the interior which terminate in attenuated borders—and I hold that there are more than one of these—are more ancient than the drift which terminates in the recognized ridged moraines. I conceive that these differently disposed drifts indicate somewhat widely separated epochs of glaciation, attended by differences of orographic attitude and differences in the specific methods of action and in the phases of deposition.

If there be any truth in these views it becomes important to distinguish the differences in the character of the border, for they have significance beyond the mere fact of variation in the manner of deposition. While not disposed to urge the acceptance of these views beyond the point to which they seem to be borne out by specific evidence—which can not, obviously, be here cited—it seems important that the differences in the nature of the border be duly weighed, and that pending the demonstration of the truth the mind of the reader be withheld from the unconscious acceptance of the impression, which has somewhat obtained, that the border is a historical unity.

Respecting the question of mode of formation it is most important that the criteria of discrimination between deposits held to be formed directly by land ice and those held to be formed by floating ice should be rigorously scrutinized. The criterion of *striation*, as urged by the author of this bulletin, appears to me to be thoroughly trustworthy where the scorings are developed in sufficient abundance and perfection to afford ample facilities for discrimination. In the Atlantic and Appalachian regions and over large portions of the interior the phenomena of *striation* are adequate and decisive, but near the border, in the plain region of the interior, *striation* is relatively rare and feeble. Besides, there are very numerous instances of unabraded, rotten-surfaced rock, covered with the ancient residuary material, and even old soils remain unremoved. This appears to force the alternative of either dismissing the land-ice theory for these areas or of maintaining that land ice may creep over extensive tracts without forcefully abrading the surface, even when already incoherent from disintegration. While I incline to the latter alternative somewhat strongly, it appears to me to be in the interest of ultimate progress to distinctly recognize the differences between such areas of feeble abrasion and those which exhibit

¹Using the word here only in the sense of a terminal *ridging* produced by a glacier.

strong glacial rasping, and also to recognize that while the land-ice hypothesis is unassailable in the one region, its support is relatively weak and perhaps altogether insufficient in some portions of the other; and further to recognize that while the glacial theory may be true in the main it may be false in the particular.

The evidence afforded by the tills seems to me yet to need adjudication. While, generally, unassorted, unstratified boulder clays are strong presumptive evidence of glacier origin, there seems yet to be reason to believe that almost precisely similar deposits may be produced by the droppings of floating ice. Certainly the presence of glaciated pebbles and boulders is not distinctive, for floating ice derived from the edge of an adjacent or distant glacier would bear material precisely like that carried within the glacier itself. That it might be unstratified in its deposition appears to be supported both by theoretical considerations and by observations on deposits which are so sandwiched between assorted and laminated material, so graduated into such material, and so bordered by beach lines and surfaced by plane topography as to afford strong evidence of glacio-natant origin. Having, without much satisfaction, puzzled over the problem for several years in the endeavor to find trustworthy lines of discrimination between bowldery clays of glacier and of glacio-natant origin, respectively, I am inclined to regard this line of proof as of doubtful character in its general application, though the specific nature of individual deposits may disclose their origin with reasonable certainty.

Evidence drawn from the topographic relations of the margin of the drift is of the first order of importance. In the present case the undulations of the margin over heights and across valleys constitute the strongest feature of the evidence. The free manner in which the border line rises and falls in crossing the Appalachian Mountains and the bordering hilly districts is scarcely less than demonstrative in itself. In the plainer regions of the Mississippi Basin similar evidence, though less pronounced in character, carries corresponding weight. Relying chiefly on this argument, a qualified assent seems required to the view of Prof. Wright that the extent of the ice was essentially coterminous with the extent of the drift.

Other criteria of discrimination between the products of land ice and of floating ice, respectively, are assignable. Among these the peculiar character of the products of drainage, particularly the overwash aprons and the moraine-headed gravel trains, have the highest value. Where these are strong and sharply developed, nothing can be more convincing of glacier origin, and nothing more fatal to the glacio-natant hypotheses. But if phenomena of this class are clearly developed in the debatable territory, they have not been determined with sufficient definiteness to be a source of appeal. On the contrary, the most notable attendant phenomenon is the loess like silt that overspreads the margin and the adjacent regions, both within and without the border. The graduation

of this into the till of these districts—*not everywhere*—I esteem one of those features which demand a conservative attitude respecting the part played by creeping ice and by floating ice, respectively.

As a check in the opposite direction, it is to be noted that there is, thus far, a lack of evidence of shore lines, or of definite horizontal limitations of the supposed subaqueous products, such as might reasonably be expected under the hypothesis of subaqueous deposition.

While, therefore, on the whole, the evidence seems to me quite strongly to support the view advocated in this paper, that the advance of the land ice was essentially coincident with the margin of the bowldery drift, such a view seems tenable only on the hypothesis that the land ice was competent to creep out upon a plain without forceful action upon it, and without notably plowing up material at its edge.

This seemingly necessary qualification respecting the marginal action of the ice must be carried with us as we turn to the consideration of the supposed glacial dam in the vicinity of Cincinnati. I assent to the view of Prof. Wright and of the earlier students of the drift south of the Ohio River, notably Dr. George Sutton,¹ that the ice sheet probably pushed across the river and landed the bowldery drift south of it essentially in its present position. But there is a lack of evidence that this involved forceful or vigorous action, for striation and abrasion have not been detected, and the amount of transported drift is trivial. The glacial action here appears to have belonged to the ineffective class above alluded to. *The fact, therefore, that the ice bridged the chasm of the Ohio does not necessarily carry with it the view that it blocked that chasm to the exclusion of the river.* It does not follow that there was a permanent glacial dam at that point, competent to backset the water to the height of the five or six hundred feet requisite to give it some other outlet. It may be admitted as extremely probable that the temporary damming of the stream by ice gorges was of frequent occurrence, and still be held that, in the main, the water maintained a tunnel under the overbridging ice. Such tunnels are not uncommon beneath existing Alpine glaciers, where they push across the mouth of tributary valleys. There is a wide distinction to be drawn between the obstruction caused by the thin extremity of a glacier creeping across the channel of a stream, and those instances (so numerous on the northward slopes during the later stages of glaciation) in which an enormous mass of thick ice, if not the great body of the glacier itself, pushed against the ponded waters. The Mergelen Lake, of Switzerland, is one of the few known instances of an ice-dam and body of water of the former order, and we have in it some indication of the competency of ice to act as a permanent dam under such conditions. The great Aletsch Glacier flows across the mouth of a tributary valley and dams back a brook, forming a little lake, to which the name Mergelen See is given. The glacier extends past the mouth of the tribu-

¹ Proc. Am. Assoc. Adv. Sci., 1876, pp. 225-231; Geol. Survey Indiana, 1878, pp. 108-113, Bull. 58—2

tary about 9,500 meters, and proves itself competent to form a temporary dam, but not a permanent one, though the depth of the backset water is here only about fifty feet. This comparatively slight depth of water, giving a pressure of little more than an atmosphere and a half, periodically bursts its way out beneath the ice, and discharges itself in destructive floods down the valley. In the supposed ice-dam at Cincinnati, the pressure reached, by hypothesis, sixteen or seventeen atmospheres, or about two hundred and fifty pounds to the square inch, while the ice reached across the gorge scarcely more than twice the distance that the Aletsch Glacier passed beyond the mouth of the valley in which the Mergelen Lake lies.

Besides the great difference in the depth of water, there is the important fact that the Ohio Valley at all times bore a stream of great volume. In proportion as the ice encroached upon its channel, its current must have been accelerated, and its scouring ability increased, and with that arose an increased tendency to cut for itself a special narrow and deep channel less readily invaded by ice. Besides, the current must have been charged with sharp silt, derived from the glacial grinding on the north side of its basin, while the water from its southern side probably at all times retained some melting power, which, added to the heat of friction developed by the constricted and forced current, augmented its ice-cutting power and aided it in maintaining itself against the ice encroachment. Its situation in the bottom of a deep gorge, running transverse to the ice movement, and lying from four to six hundred feet below the plateau on which the overriding ice chiefly rested, also gave it an advantage in maintaining itself against the thin and relatively inert margin of the ice. Thus several conditions favored the stream in its struggle with the supposed encroaching glacier.

There would, however, seem to have been every requisite condition for the formation of gigantic ice-gorges at the time of the vernal breaking up of the river ice, and on other favoring occasions. But as soon as such an ice-gorge becomes an effective ice-dam, if it ever does—which is doubtful—it destroys the conditions of its own creation; first, by stopping the current that produced it and held it in place; and, secondly, by lifting the ice by the rise of the ponded water. It seems improbable that a lake so ponded would rise to a height of five or six hundred feet without lifting such a dam of blocks piecemeal, or even bodily. Certainly, with the known tendency of solid ice to form bergs, it could not be supposed to remain long.

But, as a matter of fact, it would probably never become a complete dam, and would soon be threaded by innumerable tunnels, whose gradual enlargement would lead to its destruction. Meanwhile, the escaping waters, though greatly reduced, might still be able to maintain a tunnel under the glacier, which, though it might be correspondingly reduced by the encroachment of the ice, would again be enlarged by the

powerful current forced through it when the ice-gorge weakened or lifted.

It appears far from clear, therefore, that the existence of a permanent ice-dam was a necessary or even probable consequence of the slight crossing of the gorge by the glacier. Temporary and partial blocking should deem an extremely probable and frequent occurrence, but not permanent damming.

I am perhaps influenced in this view by a study of another region where the similar question of glacial damming has arisen. I refer to the driftless area of the upper Mississippi, which is surrounded on all sides by a deep sheet of drift. On the south, along the Mississippi, which was its drainage outlet, the country is occupied by drift for 250 miles; not merely a sprinkling of dispersed boulders with exceptional patches of till, as in the trans-Ohio region, but a general mantle of drift. The driftless area has been diligently searched for evidence of temporary as well as permanent submersion. Along the western border there are scattered erratics and a mantle of loess, but over the central and eastern portions erratics are absent, except in extremely rare instances of probably human transportation. There is a very thin discontinuous distribution of fine silt mingled with the residuary soil and only distinguishable from it in most cases by the microscopic detection of minute particles of crystalline silicates and other minerals which are common to the drift and loess but not known to occur in the purely residuary soil. These foreign particles may, perchance, be wind-drift importations, or they may be the results of transient submersion; such a submersion as was possibly due to the temporary blocking of the outlet by ice. The distribution of the loess, however, does not form an argument for this view, for it spreads over the drift southward, reaching entirely across the glaciated tract. Whatever may be the truth respecting these trivial silt deposits, there has been found no proof of general and permanent submersion of this region by ice-damming, notwithstanding the conditions seem to have been exceptionally favorable therefor, and notwithstanding the further fact that the depth of water requisite for the submersion of most of the area is less than that postulated for the supposed Cincinnati dam.

But these theoretical considerations are less to our present purpose than a consideration of the direct evidences of the existence or non-existence of an effective blockade of the river at that point. Among the crucial tests of such a hypothesis may be enumerated the existence of lacustrine deposits and high shore-marks in the valley above, *but not below*. In an ideal case such lacustrine deposits and shore-marks should be present immediately above the dam, but not present within the area occupied by the dam nor immediately below. Terraces and supposed lacustrine deposits two or three hundred miles above are less conclusive, because of the possibility of intervening agencies.

A second crucial test of the hypothesis is to be found in the existence or

non-existence of the abandoned channel through which the supposed ponded waters discharged themselves. It must be quite evident, upon consideration, that the ponded waters could not have had a permanent outlet across the ice itself, for such a stream as the Ohio, fed during the summer season with relatively warm waters from the southern half of its large basin, must quickly have cut a channel through the barrier. As yet no such outlet has been found, or, at least, determined to be such, and the hypothesis lacks this very important support.

These considerations lead up to the much discussed terraces of the upper Ohio, Monongahela, and Alleghany valleys, which have been thought by Professors Wright, White, and Lesley to have had their cause in the supposed ice-dam, and in turn to afford evidence of its existence. As a widely different interpretation of the origin of the chief terraces of these streams seems to me required, it is the part of candor to specifically set forth this divergence of view in transmitting this bulletin to the scientific public.

I look upon the determination of the origin of these terraces as chiefly a question of identification of structural species, quite analogous to the identification of species of plants and animals. Terraces formed by bodies of standing water are specifically different from those formed by flowing water, and the question here is, Have these terraces the inherent characters of lake and sea terraces or those of river terraces? The following are among the specific differences which should enable us to distinguish the class to which they belong. They are drawn with special reference to terraces in a system of branching, narrow valleys, as in the case in hand. They would require some amplifications and qualifications for a different habitat.

Lacustrine terraces are horizontal, while fluvial terraces slope in the direction of the river flow. In the case of terraces formed by rivers that have nearly reached their base plains the slope is obviously slight, but the basis for discrimination still remains. The intervention of crust movements may obscure, but can scarcely obliterate, the distinction, for in a system of tortuous and branched valleys, as in the present case, the system bears in itself the data for the elimination of the distortion.

Limiting attention for the moment to constructive terraces, it is the rule that lacustrine terraces are built throughout the entire circuit of the lake, while fluvial terraces are built only in favoring lodgment spots, as the concave bends of the meandering stream. The tendency in the one is to uniformity of distribution; in the other to local aggregation. Both tendencies are subject to important modifications, but these modifications are likewise distinctive. The two more important modifications are caused by (1) the difference in the extent of the sweep of the waves, and (2) by the material brought in by tributaries.

(1) Other things being equal, lacustrine terraces (whether wave-cut terraces or wave-built terraces) are greatest opposite the longest sweep

the waves, and, the sweep being equal, are greatest opposite the sweep of predominant winds. The strength of development of lacustrine terraces corresponds, therefore, to the stretch of water opposite to them and to their relation to prevailing winds. In river terraces wind action is overshadowed by other agencies, and the above correspondences are wanting. The more extensive the series of terraces and the more varied their positions relative to the extent of water surface and to the direction of winds the more pronounced these distinctions.

(2) Tributary streams and ravines, by pouring in detritus, form local enlargements of the terraces of lakes, and usually also of rivers, but the special disposal of the material is different in the two cases. In a lake a delta terrace is formed symmetrically about the entrance of the tributary—subject to the accidents of the situation—the material fanning out equally to the right and to the left and being thrust out in front into the lake by the force of the entering stream. In a river the material thrown in by a tributary is carried down stream and may be entirely borne away. In any active river the formation of the delta is checked on the upper and front sides and its growth directed down stream in a more or less bar-like fashion.

(3) In the lacustrine class, the wave-cut terrace, the sea cliff, and the wave-built terrace are situated together, the material for building the last being derived from the erosion of the others. On the other hand, the river-cut cliff is usually at the convexity of the river bend or at least at some point where it impinges on the adjacent highland; while the correlative river-built terrace is in the concavity of the bend below, or at least in some suitable lodgment spot, invariably down stream.

(4) The material of lake terraces is usually different from that of river terraces. In narrow land-locked lakes very little attrition of shore material is possible, and the terraces either consist of fine material or of little-worn rock fragments. Moreover, the little wearing observed is of the beach order rather than that of stream-rolling. On the other hand, the material of river terraces is stream-rolled and current-assorted alluvium. This distinction fades out in proportion as the river, by the slackness of its stream, approaches stagnant, lake-like conditions.

The foregoing statements have reference to temporary lakes occupying river valleys for a limited time, and so merely developing terraces along their slopes, but not filling up their beds. If the entire bed was filled up, and the terraces, instead of being formed directly by the lake or stream, were carved out by subsequent erosion and the question becomes one of deposition and marginal erosion, and not of terrace formation, some of the above criteria become inapplicable while others gain in force. The evidence from cliffs and rock shelves becomes stronger because in the longer lapse of time involved the differences between the laws of lake-cliff formation and of river-cliff formation more fully expressed themselves.

So, also, the distinction of material becomes more pronounced; for as

the filling of a lake progresses it retires from the bordering slopes and isolates itself in its own deposits, and the material becomes more and more distinctive and more fully assumes the lacustrine phase of assortment and lacustrine habit of stratification and thus distinguishes itself from fluvial deposits.

These statements of criteria lack both in fullness and in qualification. The distinctions will not always be sustained in a rigid application, under all conditions and in every local instance. Absolute and invariable distinctions will not be expected by experienced students of nature. But these criteria hold good in the main, and in the present instance they are regarded as entirely decisive.

TERRACES OF THE UPPER OHIO RIVER DISTRICT.

With a view to some preliminary determinations having bearings upon the crust changes, time relations, and drainage conditions of later Tertiary and of Quaternary times, Mr. G. K. Gilbert and myself spent twenty days in the fall of 1885 in a joint reconnaissance of the terraces and related phenomena of the Monongahela, Alleghany, Upper Ohio, and tributary valleys. Mr. Gilbert, as geologist in charge of the Appalachian division of the survey, approached the subject in search of light upon the former attitudes of the surface and possible orographic changes, and brought to the study a large experience and an acknowledged acumen in the analysis and interpretation of fluvial and lacustrine phenomena. My own approach was from the glacial side. Our impressions throughout were in the closest harmony, and I have Mr. Gilbert's assent to the views involved in the following statements:

The terraces of the upper Ohio River district embrace five classes, viz:

1. The high horizontal benches of Stevenson.
2. The upper river terraces.
3. The lower river terraces.
4. The slender horizontal terraces.
5. The structural or differential degradation terraces.

Discussion has previously related chiefly to the second class.

I. THE HIGH HORIZONTAL TERRACES.

These, so far as I am aware, were first described by Prof. J. J. Stevenson, from the résumé of whose observations¹ the following quotations are taken:

Looking now at the observations recorded in the foregoing part of this paper, we see that, although very fragmentary, they show the existence of two sets of benches, in one of which, the higher, the individuals have an almost unvarying level, whereas

¹ Proc. Am. Philos. Soc., vol. 18, 1880, p. 302, 303. Also Second Geol. Survey, Pennsylvania, KKK (Report of progress in the Fayette and Westmoreland district, Part II, the Ligonier Valley), 1878, p. 230.

or lower set the members have no definite altitude with respect to tide, such, as do the beds of the streams along which they are found. Arranged in form we have, first, the benches of the higher series :

	Feet above tide.
Seaton Ridge, Seaton Road	2,580
National Ridge, National Road	2,400
Seaton bench of Somerset County	2,323
National bench of Somerset County	2,288
Seaton bench of Somerset County	2,123
Near Confluence	1,820
National bench near Loyalhanna	1,690
Seaton bench near Loyalhanna	1,570
National bench near Loyalhanna	1,520
Seaton bench near Loyalhanna, also at Hillsborough and Beallsville.....	1,475
National Road, Washington County	1,445
Seaton Road, Washington County	1,420
Loyalhanna bench, also National Road near Beallsville and Hillsborough.....	1,380
National Road east from Brownsville	1,350
Seaton bench of Stewartstown series	1,290
Immediate bench, Dunbar Creek, Possum Creek, Greensburgh	1,270
Seaton bench of Stewartstown series, First Loyalhanna bench	1,225 to 1,240
National bench of Stewartstown series	1,195
Seaton bench of Stewartstown series	1,130
National bench of Stewartstown series	1,100

Position of low water at Pittsburgh, as used by the city surveyor's office, is 699 mean tide. * * *

Distinctions in level exhibited in individual benches of this series are so slight they may be due either to petty variations of the barometer, or to errors in reading the fact that, in every case, the highest point on the bench was sought, to determine the top of the detrital deposit. As that deposit, though very thin, is more or less from erosion, one could not, even with perfect instruments, make series of measurements which would tally accurately. The extreme of variation in No. 17, where two benches are confounded, is scarcely 18 feet, so that it is justified in regarding the benches as practically horizontal and parallel. The deposit on these benches sometimes contains a little clay, but sand greatly prevails. No rolled or polished fragments of stone occur, and such fragments as do belong altogether to rocks found in the immediate vicinity. Nothing like running water had ever passed over those plains, so that if the water had been its effects must have been confined within a limited space.

Portions of these terraces were examined by Mr. Gilbert and not with sufficient detail nor over a sufficient extent of area to justify us in publishing any opinion regarding them, especially as it does not concern us here; for, if I have not altogether misunderstood the advocates of the Cincinnati ice-dam, this series of terraces is included among those ascribed to that agency—indeed, this series I think, even been alluded to in the papers on that subject. Still there are insuperable objections to such reference, for, in the first place, the lowest of these is higher than the summit of the ice dam, and, in the second place, the vertical range of the series is the reverse of that of the ice obstruction. A series of terraces reaching

from 1,100 feet to 2,580 feet above tide could not rationally be referred to an ice-dam ranging from 440 feet (low water in the Ohio at Cincinnati) to 950 or 1,000 feet above tide. A dam of 500 feet would scarcely make a series of terraces having a vertical range of 1,430 feet.

II. THE HIGHER RIVER TERRACES.

These have been described and discussed, either locally or areally, by Prof. J. J. Stevenson,¹ Prof. I. C. White,² Prof. J. P. Lesley,³ Mr. H. Martyn Chance⁴ and Prof. G. F. Wright.⁵ The whole system has not yet, however, been thoroughly examined, and a complete and entirely satisfactory discussion is not yet possible, but the leading features are determinable. The term "river terraces" was applied to these by Professor Stevenson, and indicates the interpretation which he placed upon them. A similar view was evidently entertained by Mr. Chance for the portion which he has described. In this view we also concur, and hence retain the name. It seems necessary, however, to distinguish these from a lower series of river terraces of separate origin and history. Among the distinguishing characteristics of the higher river terraces are the following:

(1) *The slope with the present streams.*—This tendency is well expressed by Stevenson:

The river terraces fall down stream and are covered by irregularly bedded sand, clay, or gravel, containing transported fragments, which have been rounded by the action of running water. When followed up the streams these terraces show differences among themselves in degree of slope, so that each is merged successively into the next higher, until that which at the mouth of the stream is the river "bottom" becomes the only terrace, and is lost at last in one of the lower horizontal benches.⁶

In the following table an attempt has been made to collect all observations at command relative to the chief upper terrace of this series on the Monongahela River, and also the uppermost limit of pebbles, as these constitute the most trustworthy and significant data:

¹ Second Geol. Survey Pennsylvania, K, Green and Washington Dist., 1876, pp. 11-19; KKK (Ligonier Valley), 1878, pp. 251-263; Proc. Am. Philos. Soc., Phila., vol. 18, 1880, pp. 289-316; Am. Jour. Sci., 3d series, vol. 15, 1878, pp. 245-250.

² Second Geol. Survey Pennsylvania, Q, Beaver River Dist., 1878, pp. 9-14; also, QQ, 1879, p. 10-12; Proc. Am. Assoc. Adv. Sci., thirty-second (Minneapolis) meeting, 1883, pp. 212, 213, and Science, vol. 2, 1883, pp. 319, 320.

³ Second Geol. Survey Pennsylvania, Q, 1878, pp. xxiv, xli.

⁴ Second Geol. Survey Pennsylvania, VV, Clarion County, 1880, pp. 17-21.

⁵ Boston Soc. Nat. Hist., 1887; Am. Naturalist, vol. 18, 1884; Am. Jour. Sci.

⁶ Stevenson: Proc. Am. Philos. Soc., vol. 18, 1880, p. 314.

observations on the upper pebble-bearing terraces and upper observed limit of pebbles on the Monongahela River, given in descending order.

Locality.	Upper pebble-bearing terrace.		Upper observed limit of pebbles.		Observer.
	Above river.	Above tide.	Above river.	Above tide.	
	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>	
town, W. Va	275	1,065			I. C. White.
a State line and Georges Creek	280	1,055			J. J. Stevenson.
orough	275	1,050			Do.
of Muddy Creek	260	1,025			Do.
isels (abandoned channel)	250	1,015			White.
in run	300	1,063			Stevenson.
ville (2 miles above)	230	970	250	990	Chamberlin.
as (1 mile above village)	180	920	215	955	Gilbert.
e Wood's run (sloping shoulder)	180	920	200	940	Gilbert and Cham-berlin.
ytown	180	920	195	935	Do.
City (back of)	180	920	200	940	Do.
a Fayette City and Belle Vernon doned channel—oxbow)	200	940			Do.
le back of Belle Vernon (aban- channel).	195	935	220	960	Chamberlin.
e Belle Vernon	180	940	185	945	Gilbert.
ernon	180	940			Stevenson.
ahela Cemetery	190	920	200	930	Gilbert and Cham-berlin.
Elizabeth	185	905	210	930	Do.
port	190	910	205	925	Do.

grouping of the terraces in this way is not intended as a mode-
tion that they form a single simple series. Under the view that
river terraces it is by no means necessary to suppose that they
equivalent to one another. On the contrary, it is rather the
streams to form different sets of terraces along their course as
It of the unequal resistance of the strata, of the modifying effects
taries, and of other agencies which effect unequally the progres-
pening of the river bed. The observations in the Monongahela
ever, seem to show with some degree of force that there is a
equivalence and that the whole series declines, and this is pre-
representative of a declining limit of action on the part of the
ng agency. It is not, of course, insisted that the observations
er exhaustive or that the altitudes are strictly accurate, all being
tric determinations.

tributaries of the Monongahela River bear terraces which are
ant, but concerning which the data are more limited. The more
ole of the observations of Profs. Stevenson and White are here

Respecting Georges Creek, which enters the Monongahela River a few miles north of the West Virginia line, Prof. Stevenson says:¹

Along this stream the third and fifth benches of the Stewartstown series are persistent, but rise so that at Smithfield the fifth is 304 and the third 200 feet above the river at the mouth of the creek. * * *

Between Smithfield and Uniontown the third, fifth, and sixth benches are seen to be persistent along the east side of Brush Ridge, which marks the course of the Saltsburg axis. But in ascending the creek, the fifth has shown a constant increase in elevation, so that as the divide between Georges and Redstone Creeks is approached, that bench takes the place of the sixth, and finally becomes merged into the seventh.

Of the benches on the Youghiogeny River the same writer says:²

At McKeesport the river "bottom" is 765 feet above tide; from that point it is continuous to Connellsville, at the mouth of the Chestnut Ridge Gap, where it is 894 feet above tide.

Opposite Connellsville a fine bench is seen at barely 200 feet above the stream, which is covered by a thick coat of debris containing many huge fragments, all of them having rounded surfaces. The same bench occurs at Perryopolis, where at one time sand was obtained for glass-making.

This terrace rises much more slowly than the river bed above Connellsville, for at Ohioypyle Falls it is barely 140 feet above the river. While this bench was the bed the river flowed directly across the neck of the peninsula at the falls.

The railway elevation of Ohioypyle is given as 1,237 feet above the ocean, but what is the relationship of this to the river or to the terrace is unknown to me. The terrace at Connellsville is 1,066 feet, while the upper limit of pebbles at the mouth of the Alleghany is 925 feet high, showing a very notable fall down-stream.

Prof. I. C. White makes the following statement respecting some of the upper tributaries of the Monongahela River, which seems to conflict with the general tenor of the above data, and which will be referred to in another connection:³

The other tributaries of the Monongahela on which the writer has noticed clay and other deposits of the fifth terrace are Decker, Dunker, Whitely, Muddy, and Ten-Mile Creeks, and in each case the deposits disappear at the same absolute level at which they cease along the river.

It may be remarked, however, (1) that the criterion here observed is not rolled pebbles, but clay and other deposits, making it uncertain whether the terraces belong to the system under consideration or to some other; and (2) that these are all small streams contiguous to each other, whose terraces might have approximately the same upper limit under either the fluvial or lacustrine hypothesis.

Respecting Chartiers Creek, a stream running parallel and contiguous to the Monongahela and emptying into the Ohio, the following statement is made:

¹ Second Geological Survey, Pennsylvania, KKK, p. 256.

² Ibid., p. 259.

³ Paper read before the American Association for the Advancement of Science, Minneapolis, 1893.

continuous along Chartiers Creek from Cook's station to Bridgeville, and rafton station stands, shows the following slope of its level :

	Feet.
ion terrace, above creek at Cook's station.....	25
terrace, above creek at Bridgeville	75
ion terrace, above Creek at Bridgeville.....	205
rtiers Creek itself	180
terrace level itself.....	130

As that no one of these terraces is by any means on a dead level. These valley terraces continue to its head, and contain limestone drift from the

four's Run [a parallel stream running northerly and emptying into the milar terrace is seen, which is even more marked than that on Chartiers is traceable along the stream for several miles between Findlay and North wnshhips of Alleghany County, and falls less rapidly than the bed of the fference being about 35 feet in 4 miles. It shows many rolled and water nents, even so far from the river as Findlay township. Between Robinson townships of the same county it is much interrupted, and the attempt to its relation to the river series was not altogether successful. It seems to ed with the one occupying the third place in the list already given.*

g to the Alleghany River, it should be borne in mind that it course almost directly opposite to that of the Monongahela ciated streams, and is thus extremely well situated for the of the present discrimination, for, on the fluvatile interpreta- terraces must slope in a contrary direction. The data at com- e embraced in the following table :

Observations on the upper pebble-bearing terraces and the upper observed limit of pebbles on the Alleghany River, given in descending order.

Locality.	Height of upper pebble-bearing terrace.		Upper limit of pebbles.		Observer.
	Above river.	Above tide.	Above river.	Above tide.	
.....	<i>Feet.</i> 230	<i>Feet.</i> 1, 395	<i>Feet.</i> 250	<i>Feet.</i> 1, 415	Chamberlin.
.....	295	1, 390	.....	.....	Do.
.....	260	1, 270	.....	.....	Gilbert.
.....	250	1, 105	275	1, 230	Gilbert and Cham-berlin.
ned channel near Parker.....	250	1, 090	.....	.....	H. M. Chance.
ned channel near Parker (col xbow").	260	1, 115	.....	.....	Gilbert and Cham-berlin.
e, on the Ohio, 5 miles below mugh.	310	1, 005	.....	.....	I. C. White.
own, on the Ohio, 12 miles below mugh.	250-280	940-970	.....	.....	Wright (this paper).
.....	350	1, 040	Occasional pebbles.	.....	Stevenson.

* Second Geological Survey of Pennsylvania, Q, p. 26.

* Ibid., K, 1876, p. 15.

The two localities on the Ohio River have been added to the Alleghany series because they contain northern drift pebbles in common with the latter. By comparison it will be seen that the fall from the pebble limit at Warren to the pebble-bearing terrace at Tidionte, a distance of 21 miles, is 25 feet, the descent of the present stream being 78 feet. From Tidionte to Oil City, a distance of $35\frac{1}{2}$ miles, the fall is 120 feet, the present descent being 113 feet. From Oil City to the upper pebble limit at Parker, a distance of $49\frac{1}{2}$ miles, the fall is 140 feet, the descent of present stream being 125 feet. From Parker to Bellevue, a distance of $87\frac{1}{2}$ miles, the fall is 125 feet, the present descent being 165 feet.

The foregoing facts, if they justify any conclusion at all, sustain the view that the terraces of the Alleghany River flowing from the north slope southward, while those of the Monongahela flowing from the south slope northward toward their common axis, the Ohio River, precisely as the river terraces do to-day, and at gradients not greatly different.

(2) *The material capping the terraces is distinctly fluvial.* In narrow, winding lakes, such as those must have been which occupied these river valleys if such lakes existed at all, there could have been no great wave force, and consequently no considerable coarse-rolled material, and from the nature of the case, such rounded material as may have been produced must have possessed the well-known characteristics which distinguish lacustrine from fluvially rounded material. But the capping of the Monongahela terraces, and more notably that of the Alleghany terraces, contain large quantities of coarse, well-rolled, and I do not hesitate to say, distinctively river-rolled, material ranging from the finer grades up to boulders 1 or 2 feet in diameter, and occasionally larger. I measured one $1\frac{3}{4}$ by $2\frac{3}{4}$ by 3 feet. Prof. Stevenson records one whose dimensions were 1 by 2 by 4 feet. Both of these were on the Monongahela terraces, where the average coarseness is less than that of the Alleghany terraces. It is true that associated with this coarser rolled material there is much that is finer and indistinguishable from lacustrine material, but that is usually true of fluvial deposits. Such fine material may be said to be an inevitable element of alluvial deposits of low slope, since portions of the river flood must necessarily be relatively stagnant. In the deposits of the great floods of the Ohio at the present day a considerable proportion is of the fine, silty, quasi-lacustrine character.

There are also associated with these terraces deposits of stony clay, not very far removed in kind from the stony clays of the glacial drift, save that the embedded stones are not glaciated. This formation is susceptible of misinterpretation, but its true analogue may be seen in the banks of the present Monongahela, throughout the lower half of its course. The material there is very largely composed of a stony clay concerning whose origin there is no room for doubt. The overflows of the flood season bear out upon the submerged flats chiefly silt, but ice, stumps

of trees, and other buoyant material bear occasional stones, which are leposited with the accumulating fine material, forming a stony clay or oam. This is not at all an unusual or phenomenal deposit, but on the contrary is a typical form of flood deposit in streams of low gradient, especially in the higher latitudes, where the aid of river ice is annually afforded.

(3) *These terraces are rock platforms.* The chief terraces are rock-cut, and, as stated by Stevenson—

At every locality where an exposure occurs it was seen that the terrace is merely a shelf worn out of the stratified rock, on which the river has spread a thin layer of detritus. From the bottom of this layer to the next shelf below there is rocky escarpment, never one of detritus.¹

It would be a misinterpretation to infer from this language that there are continuous rock shelves cut along the whole face of the bluff; they are precisely the opposite of this, being broad platforms of rock at certain points and entirely absent at others. These platforms are not infrequently from a quarter to a half mile or more in width. To have cut these back by the simple wave-action of a narrow, land-locked, hill-sheltered lake would have required a lapse of time which I must leave the reader to estimate for himself. To my own mind, such a work under the conditions of this case is simply impossible, since the excavated material, together with the concurrent inwash from the surrounding country, must have completely silted the lake up before such an amount of erosion, or anything approximate to it, could have taken place.

(4) *The form and distribution of the terraces is of the fluvial, not lacustrine, order.* The distinction between lacustrine and fluvial terraces in respect to form and distribution was indicated in the statement of general criteria. In the last paragraph this feature was incidentally touched upon. The rock shelves, instead of lining the hillsides throughout, and being broader opposite the longer and more forceful sweep of waves, as they should have been had they been produced by a temporary lake, usually have their greatest development in bends of the stream, or in similar dynamic situations, where they have escaped subsequent erosion. It appears to us perfectly clear from an inspection of the ground that the chief of these platforms are but portions of the bottoms of the ancient river which were left in the subsequent cutting down of the channel. The most convincing evidence of this will appear under the following heading, but such broad platforms as occur at Brownsville, Yorkville, Bellevue, New Brighton, and elsewhere, with their rock bases and their rock faces, appear to us to admit of no other interpretation.

(5) *Abandoned channels—"oxbows."* But the most specific evidence of this is found in the abandoned loops of the ancient river, which, after their necks had been cut across by the stream, were left as irrefutable evidences of the status of the streams at the time they were

¹Second Geological Survey, Pennsylvania, K, 1876, p. 17.

formed. An excellent description of one of these, near Parker, on the Alleghany River, has been given by Dr. H. M. Chance,¹ as follows:

In driving east from Parker along the road leading to West Freedom, a strikingly broad and open valley is seen, and in it a small, sluggish stream, entirely disproportionate in size to the breadth of the valley.

At Hagerstown the wagon-road crosses this valley, which here bears off to the northeast, but bending around to the southeast it is again crossed by the road one mile from West Freedom.

Leaving the main road and following the valley for half a mile toward the southeast a summit is reached, on the south side of which another stream heads and flows * * * through a valley similar to the first. The divide is in swampy ground.

At Perryville the north side of the valley is steep and the south side of more gentle contour, but at Hagerstown the reverse is seen, while throughout the back of the bend, on either side of the summit, the inside of the loop presents gentle slopes facing the more precipitous rock-covered declivities surrounding its outer border.

The summit of this old valley is about 1,090 feet above ocean level, or 250 feet, more or less, above low water in the Alleghany River at Parker. It has been cut down into—if not entirely through—the Homewood sandstone, which outcrops in the valley wherever the side slopes are steep enough to expose it.

The valley is filled throughout by a deposit of river silt containing a small percentage of glacial drift, evidently reworked and redeposited by fluvial action. This silt consists of sand, gravel, and clay beds irregularly, though truly stratified—the counterpart of the silt found along the present channel of the Alleghany River. The coarser gravel beds in which water-worn fragments of the Coal Measure and conglomerate rocks largely predominate, are sometimes consolidated by a calcareous cement, thus being converted into recent conglomerates, similar to those seen along Oil Creek Valley.

A short distance below Hagerstown the stream cuts through the drift into the subjacent rocks, through which its descent is very rapid to the Alleghany River near Parker. The same feature is noticeable on the opposite side of the loop, where the stream cuts through the drift near the Monterey road-crossing.

The almond-shaped hill inclosed by this valley and the Alleghany Valley rises nearly one hundred and fifty feet above the drift deposit. It contains the ferri-ferous lime-stone and its underlying coal-beds.

A magnificent view of both sides of the valley and the included island may be obtained from the summit of the road leading to West Freedom, at a point one-half mile west from that town.

That this old valley was once part of the Alleghany or Clarion River channel can not be doubted. It evidently formed an oblong loop or bend that was probably cut through by an excessive undercutting erosion on the two opposite sides of the neck or narrowest part of the loop, just as the river is now slowly eating its way through the neck of Brady's Bend. This action may have been facilitated by the ice riding over the neck of the loop.

As soon as the river found a vent through the loop the old channel was abandoned; but during high water, and before the river had appreciably lowered its level, this old bend must have been a back channel, with more sluggish current than the new cut. Under these conditions it was probably filled with the drift it now contains.

But the present level of the Alleghany and Clarion Rivers is at least two hundred feet beneath bed-rock in the old channel, and as the river is now flowing on a false bottom fifty feet, more or less, above the true bottom of the valley, it is evident that the old channel is two hundred and fifty feet above the true bottom of the Alleghany River at Parker; or, in other words, the Alleghany River has eroded a valley two hundred and fifty feet deep, and subsequently refilled it to a depth of fifty feet since the old channel was abandoned by the main stream.

¹ Second Geological Survey, Pennsylvania, VV, 1880, pp. 17-20.

As the silt filling the abandoned water-course contains some glacial drift—pebbles worn from the Eozoic rocks of Canada—it follows that the river did not entirely abandon this channel until the commencement of, or some time subsequent to, the glacial period. The river, then, must have accomplished the erosion of this deep gorge and a partial refilling of it since the commencement of the glacial epoch, or possibly in less time.

The observations of Mr. Gilbert and myself support those of Mr. Chance in all essential particulars. Above the ancient channel the hills rise by relatively gentle, well graduated slopes, indicative of protracted erosion of the whole surrounding country, while the valleys below this horizon, with scarcely an exception, present steep declivities and often vertical rock cliffs, indicating rapid and relatively short erosion. In other words, the topographic contours above and below this horizon stand in sharp contrast, and of themselves indicate diverse histories.

The similar abandoned channel between Fayette City and Belle Vernon, on the Monongahela, presents almost identical characteristics. At Fayette City, where the present channel diverges from the ancient one, a rock face appears in the cross-section of the latter, and again at Belle Vernon, where the old channel is crossed by the new, there are steep rock faces on both sides, showing conclusively that the old channel is rock-bottomed. Besides these evidences, in themselves conclusive, the creeks that flow in the abandoned channel cut down through the alluvium into the rock along considerable stretches in the lower portions of their courses. The bed material of this old channel seemed to us to be clearly fluvial, and not lacustrine. Among this material are rounded masses, one, two, and even three or four feet in diameter.

As in the preceding case, from this old river bottom the hills rise by harmonious, well-graduated erosion slopes to the adjacent summits, 200 or 300 feet above, while below this horizon the slopes descend with steep declivities, and often precipitous faces. The plain of this abandoned channel is a horizon of demarkation between long continued general erosion above, and relatively rapid vertical cutting below. The ox-bow at Carmichael's we did not see, but from the description of Profs. White and Wright there seems no ground to doubt that it is in every way similar in character. So, also, doubtless, is Teazes Valley.

To us these are clear and unequivocal instances of abandoned river valleys, and their testimony respecting the origin of the terrace plains, of which they are the largest and best preserved remnants, is of the most unequivocal and decisive character. The fragmentary terraces left by the erosion of the stream along its general course, where it has followed approximately its ancient route, are but minor portions of a continuous river bottom, or of a series of river bottoms, formed during the progressive cutting down of the rivers.

It seems highly probable that these abandoned loops at Carmichael's, Belle Vernon, and Parker are to be correlated together and to be connected with the broader, more deeply covered rock terraces that line

the Monongahela, Alleghany, and upper Ohio Rivers, for in each of these instances there lies upon the ancient rock bottom a bed of fluvial material ranging up to 40 or 50 feet in thickness, and from these terraces there likewise spring the characteristic curves of ancient erosion sweeping over the uplands, while equally characteristic slopes or cliffs of rapid erosion lead down to the present river bottoms. The occurrence of subsidiary terraces does not essentially modify the truth of this generalization.

III.—THE LOWER RIVER (OR MORaine-HEADED) TERRACES.

The third group of terraces are sharply distinguishable from those which have just been considered, first, in the fact that, instead of being rock platforms covered by fluvial material, they are made up bodily of coarse alluvium, mainly gravel. They have their chief development in the rivers entering the Ohio from the north, and when traced up they are found to head on one of the moraines of the later glacial epoch, or at least of a later glacial epoch following at a considerable interval an earlier one. The uppermost of these terraces has for its surface plane the ancient flood deposits of the glacier-fed streams. The lower terraces have been cut out of it by subsequent erosion. Near the moraine this upper glacial flood surface may be traced continuously, rising somewhat rapidly as the moraine is approached, and passing gradually into a series of undulations which merge into the gravelly knobs and basins, and thence into the unassorted hills of the moraine. This relationship was satisfactorily observed by Mr. Gilbert and myself, separately or jointly, on Conowango Creek, near Russellburg; on the Little Broken Straw, near Freehold; on the Big Broken Straw, near Horn's Siding; and on Oil Creek, near Hydetown. On Sugar Creek, French Creek, and Sandy Creek phenomena of similar significance appear, but they are less clear in their import. On Beaver River and Little Beaver Creek analogous features are more satisfactorily displayed.

The streams of gravel starting in these morainic heads run down through the rock channels cut below the old river bottom as above described. The surfaces of these later glacial gravel streams are generally much below that of the earlier terrace deposits, but as they slope more rapidly there is no constant difference. An interval of from 100 feet to 200 feet may be taken as representative. These later glacial gravels extend below the present river beds, reaching depths varying from 40 feet to 250 feet or more, showing a considerable depth of channel before this late filling. These terraces reach their greatest height above the present stream, so far as observed, at the junction of the Beaver River with the Ohio. There the terrace rises 127 feet above the Ohio, according to a lock-level measurement by Mr. Gilbert.

Similar moraine-headed terraces occur in Ohio on the Muskingum, Scioto, and Mad Rivers and their tributaries, and seem to have their

equivalents in terraces on the lower stretches of these rivers and on the Ohio. In other words, there is a general system of deep valley gravels, arising from the moraines indicated and sweeping down the valleys, growing progressively finer in material. Out of these glacial flood deposits a system of terraces has been cut by subsequent erosion. The still later glacial episodes seem to have introduced modifying elements, but these are unimportant in this connection.

General remarks on the two systems of river terraces.—The time and manner of origin of the moraine-headed terrace plains are placed beyond question by their morainic connections. They are clearly the products of the streams that issued from the glacier during the moraine-forming epoch. The carving of the terraces out of these plains was chiefly a subsequent work, of relatively minor importance in the present discussion. The coarseness of the gravels of this series indicates vigorous drainage, which in turn implies an open valley and at least a fair gradient below. It is equally evident that terraces of a much higher level and different gradient could not have been formed at the same time. Minor side-valley terraces might have been formed at flood stages, but only to the height of the maximum floods, and these must have had the same slope as the broad flood plains.

It is clear that the upper gravel-bearing terraces were not formed at the same stage as these moraine-appended ones, for they are not only of a different type, being alluvium-covered rock platforms, but they stand high above most of the morainic heads of the later deposits and show much greater antiquity in the erosion of their surfaces. For example, at Warren the old gravels have an altitude of 1415 feet above sea-level, with a terrace at 1395 feet, while the moraine-headed flood deposits of the later epoch at Russellburg, eight miles upstream, occur at about 1275 feet. On the Beaver River the moraine-headed gravel stream has an elevation of about 830 feet, while along the valley below the boulders referred to the earlier epoch range from 900 to 950 feet, and ten miles below there is a wide rock-based terrace at about 885 feet. But these higher gravels contain pebbles of granite and other crystalline rock, whose presence is only to be accounted for through glacial agencies, and the explanation of their origin must embrace that element. It is not far to seek.

Outside of the moraine with which the lower series connects itself there lies a tract of attenuated drift, consisting of scarcely more than scattered boulders,¹ dispersed indifferently over the highlands or

¹I. C. White: Second Geol. Survey, Pennsylvania, Q, 1878, p. 10; QQ, 1879, p. 9, and QQQ, 1880, pp. 15-17.

T. C. Chamberlin: "The bearing of some recent determinations on the correlation of eastern and western moraines." Am. Jour. Sci., August, 1882, p. 96.

H. C. Lewis: Second Geol. Survey, Pennsylvania, Z, 1884, pp. 45, 71, 170, 171, 177, 179, 180, 186, 195, 200-202.

G. F. Wright: The glacial boundary in Ohio, Indiana, and Kentucky, tract No. 40, Western Reserve Hist. Soc., 1884, pp. 227, 228.

gathered in colonies. In the passing allusion cited below, I express doubt whether this extra-morainic drift, was an appendage of the moraine or an older drift, here barely emerging from beneath a later one, but which, farther west, extends far out beyond it. Subsequent studies over a wide extent of territory convince me that the latter is the truth. The evidence of this, even in western Pennsylvania, is of itself somewhat strong, but can not be discussed at length here.

Mr. J. F. Carll has presented convincing evidence that the drainage of the present upper Alleghany Basin was toward the Erie Basin in preglacial times, and that it was turned into its present course during the ice invasion.¹ Mr. Carll rested his admirable discussion with the establishment of the general proposition respecting drainage reversal, without attempting to distinguish between the episodes of the invasion. But the facts above cited show that this reversal must have taken place much anterior to the formation of the outer moraine, for the floods of that date poured down through a canyon already cut from 40 to 100 feet below the present river-bottom with the result of partially filling it with glacial gravel, as shown by the following table taken from Mr. Carll's report.

Table showing altitude above ocean level of the ancient floor of the Alleghany River.²

Locality.	Railroad levels.	Depth of drift.	Ancient floor.
	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
Warren, Warren County, Pa.	1,200	100	1,100
Irvinton, Warren County, Pa.	1,168	60	1,108
Tidioute, Warren County, Pa.	1,113	50	1,063
West Hickory, Venango County, Pa.	1,092	45	1,047
Tionesta, Forest County, Pa.	1,060	50	1,010
President, Venango County, Pa.	1,048	40	1,008
Henry's Bend, Venango County, Pa.	1,035	45	990
Oleopolis, Venango County, Pa.	1,032	45	987
Walnut Bend, Venango County, Pa.	1,023	40	983
Rockwood, Venango County, Pa.	1,016	50	966
Oil City, Venango County, Pa.	1,008	50	958
Franklin, Venango County, Pa.	988	40	948
Cochran, Venango County, Pa.	982	40	942
Fosters, Venango County, Pa.	970	40	930
Scrubgrass, Venango County, Pa.	945	40	905
Emlenton, Venango County, Pa.	905	45	860
Parker, Armstrong County, Pa.	880	50	830

Combining these with preceding data, three fluvial planes are to be noted: (1) the rock floor, which, lying 1,100 feet above the sea at Warren, declines southward, as shown in the above table; (2) the moraine-headed terrace plane which starts at Russellburg, eight miles above War-

¹Second Geol. Survey, Pennsylvania, Report III, 1880, pp. 330-355.

²Ibid., p. 337.

ren, at about 1,275 feet, and apparently about 250 feet above rock bottom, and likewise declines southward; and (3) the upper erratic-bearing terrace plane, which, starting at Warren at 1,395 to 1,415 feet, and having at Tidionte, near the ancient divide, an altitude of 1,390 feet, declines to 1,115 feet at Parkers. The time sequence of these three planes is clear. The high terraces must have been first formed as shown by Mr. Chance. The rock channel, whose bottom represents the cessation of excavation, was eroded after the high terraces were formed and before the later gravels were poured into it. The moraine-attached gravel planes were manifestly last in formation.

The higher glacial gravels antedated those of the moraine-forming epoch by the measure of the erosion of the channel through the old drift and the rock, whose mean depth here is about 300 feet, of which, perhaps, 250 feet may be said to be rock. The excavation that intervened between the two epochs in other portions of the Alleghany, Monongahela, and Upper Ohio Valleys is closely comparable with this.

In view of these facts it seems scarcely less than proven that it was the earlier invasion of ice that reversed the drainage and partially filled the valleys with *débris*, forming the capping of glacial gravel that rests upon the upper terraces.

As we read the history of events, the salient features were as follows: The erosion of the valleys proceeded with relative slowness during the stages immediately antedating the time at which the streams reached the base plane represented by the bottoms of the abandoned channels on the Alleghany and Monongahela Rivers, and the degradation of the surrounding country was relatively great as compared with the downward cutting of the streams. This became more and more pronounced until the streams (in these portions of their channels) reached base planes of erosion, after which they began to build up their bottoms by the fluvial deposits of which we now find remnants. This proceeded until forty feet or more of basal debris was accumulated. This building up of the bottoms of the streams while the degradation of the surrounding country was still in slow progress, afforded exceptionally favorable conditions for changes in the courses of the streams. The two-fold process was especially adapted to bring low necks within the limits of overflow at flood stages, or to cause the dissection of narrow necks by lateral corrasion. It does not surprise us, therefore, that several important changes took place nearly coincidently during the prevalence of these conditions.

From the fact that the fluvial material in these abandoned channels and on the corresponding terraces in the Monongahela Valley is wholly local, or southern, while among the analogous material of the Alleghany there mingle crystalline erratics of Canadian derivation, and from the evidence given above, we draw the inference that the partial filling was coincident with some stage of the earlier glaciation, presumably a late stage. This view gathers some support from the now well

sustained belief that a general depression and slackening of drainage accompanied the earlier glaciation.

Following this episode of valley-filling and earlier glaciation there was a prolonged epoch of rapid erosion of the valley bottom, which was apparently coincident with an interglacial epoch, and was, perhaps, the result of the resilience of the land after the glacial depression. During this epoch the rock gorges were cut down to the rock bottoms that now lie forty feet or more below the present river bottoms. Then came the later invasion that halted at the outer terminal moraine, whose overloaded floods, like those of the preceding glacial incursion, filled the valley bottoms with glacial alluvium; only, in this instance, in harmony with the more vigorous character of the later glaciation, the filling reached, at some points, 300 feet. Since that time there has been another stage of reexcavation, giving origin to the lower gravel terraces.

This is doubtless far from being the whole history of events, and may be divergent from the truth in minor phases, but I believe with some confidence that it represents the general truth respecting the history of the abandoned channels and chief terrace deposits of the system of benches under consideration. Were not this introduction already almost inexcusably long, I should desire to give expression to my belief in some minor episodes and to qualify these bald outlines.

Recurring to the question of the relationship of these terraces to the supposed ice dam at Cincinnati, it becomes obvious that, if the foregoing identifications are correct, the phenomena do not admit of explanation by such an obstruction. In a different way they find their elucidation in the conditions that accompanied the ice invasions. That there were at least two incursions of ice, that both had the habit of filling up the bordering valleys with their drainage matter, that a depressed condition of the land and a slackened drainage were coincident with certain stages of each, and that there was a prolonged interglacial interval of erosion, are indicated by a wide range of phenomena. In support of the lower gradient of the streams, which is the leading feature of the explanation of the much-discussed higher river terraces, there may be cited, on the one side, the extensive deposits of the loess on the lower Ohio, the Wabash, the Illinois, the Mississippi, and the Missouri Rivers, as shown by the concurrent observations of numerous geologists, and, on the other side, the yellow gravels and the brick clays of Philadelphia, the bowldery deposits about the Delaware and Chesapeake Bays, and the Columbia formation of the Potomac and adjacent regions, as worked out respectively by Messrs. H. C. Lewis, F. D. Chester, and W. J. McGee.

So, also, in confirmation of the very considerable erosion which took place between the invasions, there is, on the one hand, the great erosion of the Missouri Valley from the Great Falls, in Montana, to southern Dakota, in the course of which, for long stretches, it has manifestly cut

ts entire channel of from three hundred to eight hundred feet in depth since the early drift epoch, and, on the other hand, the erosion of the Atlantic streams, notably that of the Potomac, where the entire gorge from below the Great Falls has been excavated in obdurate crystalline rock since the earlier glacial epoch, as shown by McGee.

In short, both in the great interior basin, on the one side, and on the Atlantic coast on the other, as shown by independent observations, there appear to have been prevalent the two great features of which we find additional evidence in the terraces of the upper Ohio and its tributaries, viz: first, a general depression coincident with the earlier ice invasion, and, second, a prolonged interval between invasions, marked by greater erosion.

Respecting the argument of Prof. Wright, that the high state of preservation of the vegetal deposits indicates a recency incompatible with the great lapse of time which the erosion of the valleys implies, I have only to remark that I know of no criterion by which the minimum rate of decay or lithification of vegetal deposits takes place when the material is buried in clay or constantly submerged by ground-water. The whole tenor of the study of fossil remains is to emphasize the fact that the preservation has been extraordinarily perfect under certain conditions, while under others the completeness of the destruction has been equally phenomenal. It appears to me that the rate of decay and of lithification of buried vegetal material is a problem rather than a proof. Very fresh-looking wood is found in the *Tertiary* deposits of the lower Mississippi Valley.

IV. THE SLENDER HORIZONTAL TERRACES.

A system of slender terraces, lying along the slopes of the hills back of Wheeling, W. Va., has been observed by Mr. W. J. McGee, of the U. S. Geological Survey. With them he is inclined to correlate some of the terraces of the Monongahela River and some of its tributaries, which have been examined by him. These terraces are far from being constant, and commonly occur only at localities obviously favorable for their formation and preservation. There are usually two, but rarely three or more members, all within a vertical interval seldom exceeding fifty feet. They differ entirely from the preceding classes, being merely slender bands of slope-wash lodged along the sides of the hills, reaching a thickness of perhaps ten feet, measured normal to the hill slope, and having sloping surfaces. So far as observed they maintain a horizontal position. They seem to be just such accumulations as might gather on the margin of a ponded stream in a comparatively limited interval of time. The mean altitude, on both the Ohio and the Monongahela, is about one hundred and fifty feet.

As indicated in a quotation made above, Prof. I. C. White finds on several of the tributaries of the Monongahela clayey terrace deposits, which disappear at the same absolute level at which they cease along

the main river. It may be that these clayey terraces constitute a horizontal system equivalent to those observed by Mr. McGee, while the rock benches and alluvium capped terraces of the region belong to the ancient river system, and that in this discrimination lies the reconciliation of seemingly inharmonious observations. The data at command are far too limited to warrant a confident conclusion. These observations should stimulate a further search for this class of terraces, and in this search it is supremely important that these slender, slope-wash terraces should be distinguished from those which have heretofore been the chief, if not the exclusive subjects of discussion in this region, and with which they have little in common beyond the bald fact of being terraces.

V.—THE STRUCTURAL TERRACES.

The fifth series of terraces which mark the slopes of the upper Ohio and its tributaries are obviously structural or degradational, being dependent upon the unequal resistance of the paleozoic strata that form the hill-slopes of the river valley. They are horizontal where the strata lie horizontally and inclined where the strata lie inclined. Their origin is obvious.

SUMMATION.

Summing up the subject of the terraces, it is to be remarked (1) that the highest series of terraces are horizontal, but have elevations the lowest of which is above the reach of the supposed Cincinnati ice-dam, and the range of which, according to Prof. Stevenson (on whose observation the determination of the whole series rests), greatly exceeded the total range of the ice-dam, and that the two, for other and obvious reasons, can have no causal relationship; (2) that the upper series of pebble-bearing terraces carry evidences that to us are clear and decisive that they are fluvial in origin and that they were contemporaneous with the earlier glacial epoch; (3) that the lower series of gravel terraces are demonstrably connected in origin and in time with a later ice incursion, during which was formed the outer moraine which has been so carefully traced by Profs. Lewis and Wright across northern Pennsylvania; (4) that the slender horizontal terraces observed by McGee (and perhaps certain portions of those observed earlier by Prof. White, but not separated in discrimination from the fluvial terraces), may be the relics of the work done by the waters ponded by the glacial obstruction at Cincinnati; but too little is yet known of these to justify more than this suggestion; and (5) that the structural terraces are evidently due to differential degradation and have obviously no relationship to the question under discussion.

THE GLACIAL BOUNDARY IN WESTERN PENNSYLVANIA, OHIO, KENTUCKY, INDIANA, AND ILLINOIS.

BY GEORGE FREDERICK WRIGHT.

INTRODUCTION.

The following is a preliminary report of progress concerning my investigations relating to the glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois. But as, according to instructions, the work is supplementary to what had already been done in the same field, it has been necessary to give a summary statement of facts previously discovered and published.

The main problem has been to determine by actual observation the exact southern line along which the signs of the so-called direct glacial action cease to be apparent. To accomplish this it has been necessary to examine personally a belt of territory along the whole distance sufficiently wide to demonstrate that the phenomena denominated "glacial" actually exist down to the line, and that they do not exist south of the line.

The phenomena chiefly relied upon as proofs of direct glacial action are the existence of striated surfaces of rocks in place, the occurrence of the unstratified deposits called "till," and the discovery of transported boulders in such positions as to preclude their deposit by water action. The sufficiency of this proof can be evident only from the report itself. As there may be occasion to question the character of the deposits called "till," I have inserted in the text cuts from photographs of several fresh perpendicular exposures in different places.

STRIATED SURFACES OF ROCKS IN PLACE.

There is no question that an exposed surface of rock might be striated by the action of a vast mass of floating ice in shallow water. Icebergs whose lower surfaces barely graze the rock beneath, and which are moved along by strong and steady currents of water, might produce striæ which are in a general way parallel with each other over extended surfaces of level country. But that the striation char-

acterizing the greater part of the drift-covered portion of North America could not have been produced by floating ice is evident from a variety of considerations.

In the first place, striated surfaces are found in situations where it is impossible to suppose there could have been any currents of water in which ice could float; and the striæ in these places correspond in all respects with those ordinarily found in other situations. For example, limiting myself to observations of my own, in Davidson township, Sullivan County, Pennsylvania, there are numerous and well-defined striæ upon the exposed surfaces of Pocono sandstone, lacking only a few hundred feet of being as high as the highest summit of the Alleghany Mountains, and not far from 2,000 feet above the sea. The direction of the striæ is here S. 9° W.



FIG. 1.—Striæ on the summit of the Alleghanies, Sullivan, Pa.

A few miles west in the valley of Muncy Creek, there are other striæ at a lower level, whose direction is evidently determined by that of the valley which bears in some places S. 70° W. At a still lower level, and farther down the creek after it emerges from the Alleghany escarpment (which here, as elsewhere, bears from NE. to SW.), in Penn township, Lycoming County, the striæ turn again to a more southerly direction, bearing S. from 10° to 20° W. There is here no chance for a current of water moving over the Alleghanies to produce all these striæ; for every appearance indicates that they were contemporaneous, and water which would barely suffer the ice to graze the surface in Davidson township, Sullivan County, would be too deep in Penn township, Lycoming County, to allow a floating body of ice to graze the surface there, which is at least 700 feet lower than the other in Davidson township. Nor would there be any opportunity for a current of water to set over Penn township from the north, since the escarpment of the Alleghany is only two or three miles distant in that direction, and it is in all places from 700 to 1,000 feet above it.

Nor could this striation be the result of a local glacier, since Davidson township has no higher land to the north in which a local glacier

old form. On the other hand, everything coincides with the supposition that a continental ice-movement from the north here surmounted the Alleghanies, and that its force was nearly spent at this point. The striæ on the unobstructed surface of Davidson township represent the normal movement of the ice in that vicinity, while the variations in direction down Muncy Creek show the disturbing influence of a local alley near the margin, down which the semi-fluid mass would press in obedience to its laws of motion.

This is but an instance of what may be found in various other places in the mountain regions of Pennsylvania.¹

Phenomena similar to these just described are also not infrequently met with, making it evident that the striæ now exposed to observation were those produced by the last movements of the ice near its margin and during its period of final retrocession. Each forward movement of the ice, like that of a plane or rasp, would obliterate the marks of the previous movement.

In the region coming more immediately within the limits of the present report, namely, that lying west of the Alleghanies and extending to the Mississippi River, the observed striæ near what I have taken to be the limit of direct glacial action have been comparatively rare; still they are sufficient to illustrate the same general principle. In the places where these marginal striæ have been observed there is usually either a barrier which would obstruct the progress of a current of water flowing in the direction of the striæ, or, where there is no barrier, there is such a sudden cessation of glacial deposits as could not have occurred if the transporting agency had been floating ice. The water deep enough to have floated bergs to the locality of these striæ, and to the limit of glacial deposits not far beyond, would, in the absence of barriers, have transported this glacial débris still farther south.

Again it is noticeable that these marginal striæ very uniformly point at right angles to the marginal line itself in the locality where they occur, so that in repeated instances I was able from the direction of the striæ to prophesy the direction of the nearest point in the margin of the striated area.

For example, the striæ in Mercer and Lawrence Counties, in western Pennsylvania, have a general direction S. 45° E., which is very nearly at right angles to the line marking the limit of direct glacial action a few miles away.²

Again, in Highland County, Ohio, the average bearing of striæ is S. 80° E., at right angles again to the glacial margin a few miles away.

At Woodsdale, Butler County, Ohio, about 20 miles north of Cincinnati, well defined striæ occur, running nearly N. and S. These are of

¹ For further particulars respecting other places in Pennsylvania see Second Geol. Survey, Pennsylvania, Z, containing the report of H. Carvill Lewis and myself upon the terminal moraine in that State, especially the reports on Monroe, Luzerne, Columbia, and Lycoming Counties.

² Op. cit., p. 189.

additional interest as showing the degree to which the ice movement at this point was independent of the local topography. The striae here observed were upon the south side of the Miami River (whose general course is here NE. and SW.), and 75 feet above low-water mark. The direction of the striae is diagonal to that of the valley, which is here a mile or more in width, but nearly at right angles to the general course of the glacial boundary, about 20 miles to the south.

Near Vandalia, Owen County, Ind., well marked striae appear running from S. 40° to 50° E., some bearing still more to the east. Here, again, the limit of direct glacial action (which is but a few miles away), after having swung from Clark County, near the Falls of the Ohio, at Louisville, Ky., to the north as far as Morgan County, is now for a long distance passing in a SSW. direction toward Posey County.

The point farthest south at which striae have been observed east of the Mississippi is near the southwest corner of Williamson County, Ill., about latitude $37^{\circ} 35'$.

This is near the apex of a great southern loop in the glacial boundary, which extends but a few miles farther to the south; and the direction of the eastern set of striae, in Williamson County, is S. from 10° to 15° E., while that of the western set, about 12 miles distant, in Jackson County, is S. 5° W. The striae are here undeniable and most clearly marked.

SUMMARY OF FACTS CONCERNING THE UNSTRATIFIED DEPOSIT CALLED TILL.

PRELIMINARY REMARKS.

Full descriptions of till and its associated deposits are given by President T. C. Chamberlin in his preliminary paper on the Terminal Moraine of the Second Glacial Epoch.¹

It is sufficient here to remark, in general, that the agency through which the drift deposits are supposed to have been distributed is one which is capable of producing very complicated results. During the whole existence of the continental glacier, especially at certain seasons of the year, there must have been connected with it a great amount of water action; and through the agency of the enveloping sheet of glacial ice, water must have been set free in places and under conditions very different from those in which it would be a modifying agent after the ice had withdrawn. In all those valleys whose natural drainage is to the north there would be a period, both during the advance and during the retreat of the ice, when temporary lakes would exist in its front. In all such places, of course, there would be opportunity for that peculiar stratification of the material characterizing the deposits distributed by water. It is easy to see that these conditions would exist to a marked degree in Ohio north of the water-shed.

¹ Third Annual Report U. S. Geol. Survey, 1883, pp. 295-310.

On the other hand, south of the water-shed, where the main drainage lines were always open to the south, it would be rare that any large confined body of water could have existed for any great length of time. But wherever there was an ice front at any level there must have been, especially during the period of retreat and during the summer months, a vast amount of water set free even upon the high lands, which in its impetuous course would sort the material and deposit terraces and deltas of sand, gravel, and pebbles in positions that are quite impossible in the present condition of things. My observations have been particularly directed to the effects of this complicated agency south of the water-shed between the Ohio and the lakes, and more particularly near the southern margin of the region over which the marks of the direct action of glacial ice are unmistakable. In conducting these observations I have incidentally traversed nearly the whole region between the lakes and the Ohio in every direction, and have carefully zigzagged the whole marginal line from the Alleghanies to the Mississippi, crossing and re-crossing it at short intervals (usually from one to two miles), extending my observations over a considerable belt of the territory beyond the limit assigned by me to direct glacial action. An incidental branch of the investigation, and one which in interest and importance is so great that it well-nigh overshadows the main inquiry, pertains to the effects during and towards the close of the glacial period of water action along the valleys opening to the south, and which lie for the most part outside the glaciated region. With a remarkable uniformity these valleys contain immense deposits of gravel, which line their sides to a level far above the reach of present streams.

GENERAL DISTRIBUTION OF TILL AND ITS RELATION TO BURIED CHANNELS.

The distribution of drift material over the glaciated region south of the water-shed between the lakes and the Ohio is more uniform than it might seem to a local observer. As Prof. J. S. Newberry¹ long ago pointed out, glacial action in Ohio was superinduced upon a country whose minor topography had been shaped by the long-continued erosive action of running water. These preglacial streams had everywhere eroded channels through the sedimentary rocks hundreds of feet in depth, and south of the glaciated limit these channels are still the marked feature of the country.

North of the line the channels have ordinarily been filled with till so as completely to obliterate them. According to Prof. Newberry the Cuyahoga River (flowing north and emptying into Lake Erie at Cleveland) occupied in preglacial times a bed 200 feet beneath its present bottom, since borings along its bed for twenty miles above its mouth penetrate that depth before reaching the rock, while the rocky escarpment on each side of its present narrow valley now rises from 200 to

¹ Report Geol. Survey, Ohio, vol. 1, pp. 34, 37, 44, 172, 175, 177, 205, 418, 433, 461

300 feet above it. Previous to the glacial period this river must therefore have occupied a narrow trough from 400 to 500 feet deep. Prof. Newberry had also called attention to a buried channel occupied in preglacial times by Rocky River (a stream emptying into Lake Erie a few miles west of the Cuyahoga), but which was filled up by glacial débris, so as to compel the stream to seek another channel in the lower part of its course. Recently Dr. Gould, of Berea, Ohio, has traced this buried channel a distance of more than twenty miles, connecting it with the wide, deep valley still occupied by the stream in Medina County. The course of the buried channel is traced partly by gathering a record of wells which fail to reach a rocky bottom for 50 or 100 feet below the ordinary depth, but more especially by noting the repeated places at which the present stream in its winding course crosses and recrosses the old valley. Where this occurs the present stream flows between rocky banks both above and below the line of the buried valley, and has a rocky bottom; but in the short space occupied by the old valley itself the stream now flows between banks of till nearly 100 feet high, and has a muddy bottom.

Thus, in the main, all the valleys down to the glaciated limit in Ohio, Indiana, and Illinois have been obliterated, and the whole region has been reduced to a comparative level by the action of the ice; so that the glacial boundary is found to be practically the limit of the prairie region in these States, though as the Alleghanies are approached from the west the comparatively higher elevation of the country, and the consequent increasing depths of the river channels, makes the till in increasing degree insufficient to fill them.

The maximum for the average depth of the glacial deposit over the area in Ohio north of this boundary line is estimated by Mr. E. W. Claypole¹ to be 56 feet. No one at all familiar with the region will be disposed to think this estimate exaggerated.

Recent activity in Ohio and Indiana in boring for gas and oil has given us more definite knowledge of the depth of the glacial deposits over that region than was before possible. The result is to prove that Prof. Claypole's estimate of an average depth of 50 feet is altogether too moderate.² Prof. E. Orton furnishes me in advance the figures which he is to publish in his forthcoming report upon the subject. These figures represent the depth of the glacial deposit in fifty-three of the counties of Ohio as determined by the borings in one hundred and twenty-two wells. The average depth of the glacial deposit is found to be upwards of 90 feet (93 feet+). In some of the wells the depth of the glacial deposit was truly phenomenal, as in St. Paris, Champaign County, where in one well rock was not reached until a depth of 370 feet, while in another 530 feet was penetrated by boring, and the well was aban-

¹ See Proc. Am. Assoc. Adv. Sci., 30th (Cincinnati) meeting, 1881, p. 151.

² As to the possibilities of error in such calculation, see the driftless area by Chamberlin and Salisbury, Sixth Annual Report U. S. Geol. Survey, p. 207 et seq.

ned before rock was reached. In Dayton, Montgomery County, theacial deposit was found to be 247 feet deep; in Cridersville, Auglaize county, 300 feet; in Newark, Licking County, 235 feet; in Lebanon, Warren County, 256 feet; in Osborn, Greene County, 207 feet; in Hamilton, Butler County, 214 feet. The average in various counties is also gnificant. In Auglaize County six borings give an average depth of 11 feet; in Butler County, four borings average 116 feet.

With reference to the correctness of this representation, it should be marked that borings prosecuted in this manner are more likely to ive an underestimate than an overestimate of the real facts; for, as well known, it is much easier and less expensive to drill through the adimentary rocks than through deep deposits of till and looser drift, o that the aim of the prospectors is to begin their wells at points where e rock will be reached at as small a depth as possible. But so completely have the preglacial lines of erosion been obliterated in Ohio at it is impossible to make certain calculations as to the proximity of e rock to the surface. In the deepest drift (530 feet in Champaign county) special effort was made to locate the boring where the superficial deposits were shallow; but, as the result proved, the surface indications were deceptive and a serious mistake was made, involving he contractor in financial disaster. It should, however, be observed at the deep well of St. Paris lies in the line of the terminal moraine f the second glacial epoch, as indicated in the report of President hamberlin, where the depth of glacial deposits is supposed by him o be exceptionally great.

CHARACTER OF THE MATERIAL COMPOSING THE TILL.

A uniform characteristic of the surface deposits covering the glaci-
ted region is the intermingling of a great variety of material from
widely separated regions to the north.

The significance of the facts observed can best be perceived by com-
aring observations from extreme portions of Ohio. We will therefore
ut side by side the deposits in Oberlin, Lorain County, Ohio, and those
ear Oxford, Butler County.

Oberlin lies 12 miles south of the lake and 252 feet above it, being about
0 miles north of the water-shed. The general surface of the country is
emarkably level, though rising gradually to the south; the divide be-
ween Black River and the Killbuck, in Harrisville, Medina County,
eing but 84 feet higher than the general level in Oberlin, while the
lvide between the Maumee and the Wabash, near Fort Wayne, Indi-
na, is seven feet lower than Oberlin, and the summit between the San-
lusky and Scioto Rivers, in Wyandot County, and between the Maho-
ing and Grand Rivers, in Trumbull County, do not vary ten feet either
ay from that already mentioned in Medina County. The drainage sum-

mits between the Cuyahoga and the Tuscarawas, and between St. Mary's and Laramie Creek, are from forty to sixty feet higher still.



FIG. 2.—Map showing glacial boundary in Ohio.

The following table¹ will be convenient for reference :

Lowest summit between the waters of Lake Erie and the Ohio River :

	Feet above tide.
Mahoning and Grand Rivers, Champion, Trumbull County	918
Cuyahoga and Tuscarawas Rivers, Summit Lake, near Akron, lowered four feet by the canal	975
Black River and Killbuck, Harrisville, Medina County	911
Sandusky and Scioto, Tyamochtee, Summit, Wyandot County	908
St. Mary's and Laramie Creek, Shelby County	952
Maumee River and Wabash, near Fort Wayne, Indiana	895

The following data are of value in connection with the above table :

Elevation of Lake Erie above tide	Feet. 575
Elevation of Oberlin above tide	827

¹ Prepared by Col. Charles Whittlesey for annual report of the Secretary of State to the Governor of the State of Ohio (Ohio statistics) for 1879, p. 574.

It thus appears that there could have been no confined body of water over the northern part of the State of sufficient depth to float icebergs of any great size. So that, from the nature of the case, we could not expect to find in this region any extensive deposits from that source; and, least of all, any great amount of striation which could be attributed to floating ice, and with this conclusion the character of the drift in this region corresponds.

The rock nearest the surface in Oberlin is the Waverly sandstone, which in places is but slightly covered by drift, but in other places has suffered extensive erosion, and wells penetrating the drift thirty or forty feet fail to reach the rock. The strata are here dipping toward the southeast at a rate of nine feet per mile.¹ Eight miles to the north-east occurs the line of the outcrop of these sandstones, where are the celebrated Amherst quarries, at an elevation of about one hundred and twenty-five feet above the lake. The lower shelf between these quarries and the lake is occupied by Erie shale, concealed only by a thin covering of drift.

The 175-foot level is marked by a ridge of sand and local gravel, with occasional collections of well-rounded pebbles from three to four inches in diameter. Pieces of fresh wood (supposed to be sycamore), much water-worn, are frequently found from fifteen to twenty feet below the surface of this ridge, and are specially abundant in the level country immediately south of it. Towards the lake there are other series of ridges at lower levels, and in various places where I have observed it, there is in such situations a marked increase of granitic bowlders upon the general surface between the ridges, as if the washing of the waves had carried away the fine material leaving upon the present surface only the bowlders that were originally scattered through a deeper deposit of till, such as characterizes the whole country to the south of the ridges. The geological formations of this vicinity are shown by the following record of a recent boring:

Record of an artesian well at Oberlin.

	Feet.
Yellow clay.....	11
Blue clay.....	10
Red clay.....	10
Sandstone.....	10
Red shale.....	74
Blue shale.....	24
Black and blue shale.....	737
Limestone.....	15
Total.....	891

From this statement of the situation, the significance of the following facts concerning the composition of the drift at Oberlin will be apparent. From a number of wells dug during the spring of 1886, and

¹ Whittlesey, *Ibid.*, p. 575.

penetrating the superficial deposit from fifteen to twenty feet, it is evident that it can not have been a deposition in water. Granitic boulders brought from northern Canada, two feet and more in diameter, are frequently found at all depths in the deposit. Fragments of Corniferous limestone (finely polished and scratched), whose horizon is several hundred feet lower than the situation in which they are found, occur in the drift at all depths. The mass of the deposit is, however, a very tenacious clay, formed by the mechanical comminution of the extensive deposits of shale whose outcrop is to the north and at a lower level. A specimen of this clay, freshly taken from 15 feet below the surface, consisted of about 55 per cent of material so finely comminuted that it was readily held in suspension in water. The remaining 45 per cent consisted of fragments more or less angular, and from one-quarter of an inch in diameter down to the finest sand. Both of these portions effervesce readily in acids, showing that lime is present in the form of carbonate, and that therefore the clay is the result of mechanical comminution and not of chemical disintegration¹. We give in a note the result of both a mechanical and a microscopical analysis.² Among the materials composing this deposit there are granitic and quartzite fragments from northern Canada, Corniferous limestone from below the level of Lake Erie³, fragments of Erie shale, sometimes two or three inches in diameter, and pieces of Amherst sandstone. All these ingredients are intimately mixed together without any signs of stratification. There are, however, at irregular intervals, belts of stratification in the till wherever I have observed it. For example, in one of the wells mentioned in Oberlin a vein of quicksand a foot or more in thickness was encountered at a depth of 12 feet, but with compact blue till both above and below it.

It is evident that there is no way in which the material composing the till just described could have come into the position it now occupies except by a true glacial movement. The lower level occupied by the strata of the shale (which appears in the till at Oberlin in fragments as well as in finely comminuted particles) demonstrates that the transportation could not have been by floating ice, since with a water level low enough for the shale to have been frozen into the cakes of ice there could not have been depth enough to float it over the higher lands to

¹ See Pres. T. C. Chamberlin, in *Am. Jour. Sci.*, 3d series, vol. 27, 1884, pp. 378-390.

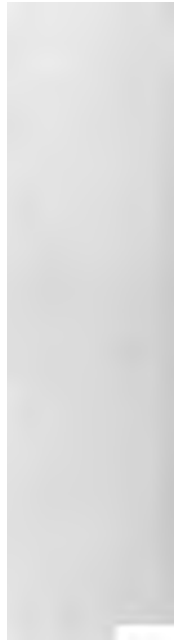
² In thirty-eight grains of the material are twenty-one grains of suspended matter and seventeen grains of matter too coarse to be suspended in water. Under the microscope the suspended matter betrays its mechanical origin.

³ These limestones, however, crop out to the northwest at Sandusky, and to the north on the other side of the lake. But taken in connection with the other facts apparent, we are warranted in drawing the inference that these limestone fragments are from the direction of the ice-flow as indicated in the abundant striae of the vicinity; and there is no reason why they should not have come from the level of other fragments with which they are associated.



SECTION OF TILL AT LANE'S MILL, NEAR DARTOWN, BUTLER COUNTY, OHIO.

1



south, where it is now found. This inference is confirmed also by comparative study of drift deposits in the southern portion of the e.

The accompanying illustration (plate I) shows perpendicular exposure of till on the banks of Four-mile Creek, at Lane's Mill, west of town, in the northwest part of Butler County, Ohio. The height of the bank is 65 feet. About half way up from the bottom there is a stratum about two feet thick, which is partially stratified; but above and below this stratum the deposit is true till, being very compact and containing a great variety of rocky fragments, showing distinct marks of glaciation. The larger portion of the rocky fragments consists of local limestones, and these are abundantly striated. These fragments range from two feet in diameter down to minute pebbles, which are readily held in solution in water. The finer portions effervesce readily in acids. This locality is also that in which fragments and logs of cedar wood are found mingled with the till. Near the left-hand corner a large red-cedar log was found a few years ago in such a condition that it was manufactured into utensils of various kinds, and it still retained its peculiar odor. Fragments of wood are projecting from the till both above and below the stratified layer.

We could not detect any essential difference between the till at this locality and that described at Oberlin, except what would be accounted for by the difference of composition arising from the difference in the local material which has been ground up to constitute the matrix. In all cases the material is largely the product of mechanical rather than chemical disintegration. Also, whatever we may say about the stratified stratum in the middle of the bank (shown in plate I), the great masses above and below are clearly the direct deposits of a glacier and deposits from floating ice. A second view (plate II) from a locality near Darrtown, is of a similar perpendicular exposure. The unstratified character of the deposit is apparent. The clay and semi-angular fragments are indiscriminately mixed. There is also a well-marked tendency in the flat limestone fragments in the lower portion of the deposit to arrange themselves horizontally. This arrangement, it is true, could, according to mechanical principles, be that which would obtain if the flat fragments were of uniform thickness and fell through a considerable depth of water. But the chances of their being of uniform thickness and the improbability of their having fallen through great depths of water are such that we may take the horizontal arrangement as proofs of direct glacial deposit rather than of deposit from floating ice.

These instances are but illustrations of what occurs at numerous points far from the border of the glaciated region as marked in my map. Essentially the same characteristics are found at Avondale station,

within the limits of Cincinnati itself, and at North Bend, on the north bank of the Ohio River, 20 miles west of Cincinnati, in a deposit 150 feet deep.

SOURCE OF BOWLDERS IN THE TILL.

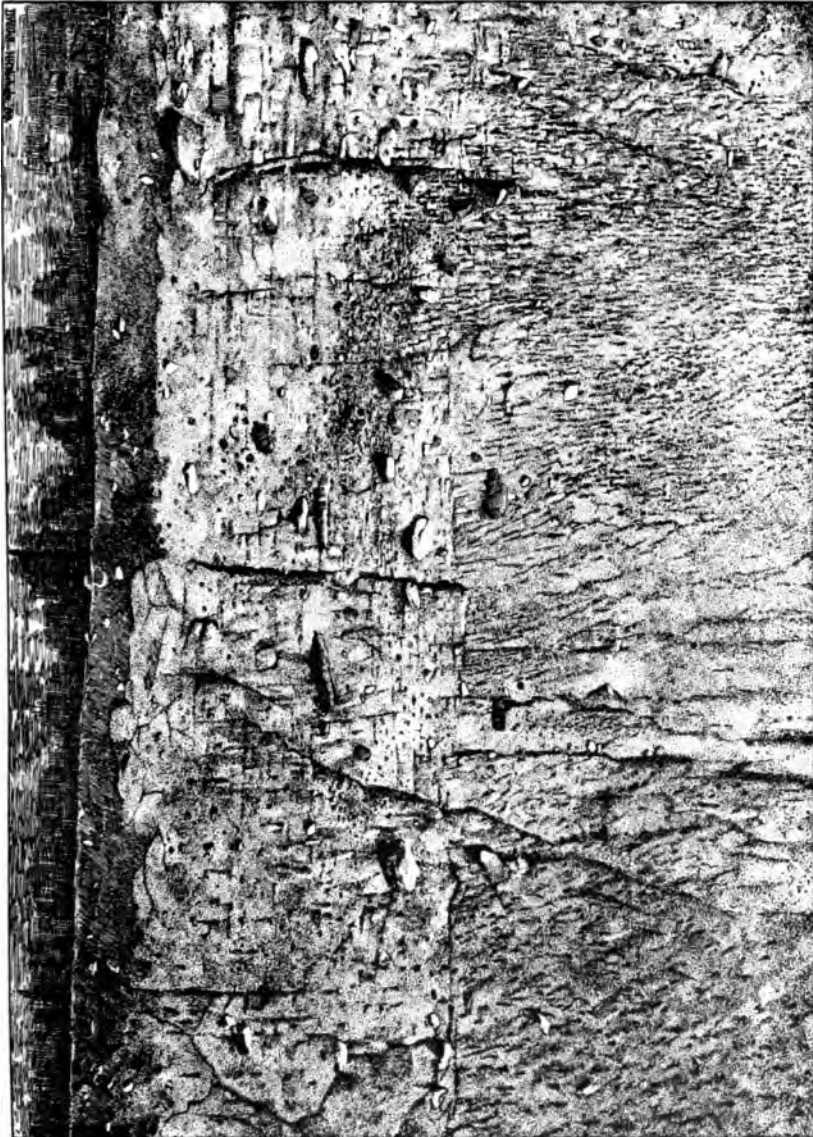
The northern origin of much of the material composing the deposits near the margin of the glaciated area is unmistakable, and some of it is surprising both for the distance it has been transported and for the size of the masses transported.

As yet there has been no systematic and complete comparison of the bowlders found near the glaciated margin and the rocky masses to the north, for the purpose of definitely locating the origin of the transported material, and there is such a degree of superficial resemblance between the granitic formations in different localities that no comparison will be satisfactory until the specimens have been both chemically analyzed and examined under the microscope. Still, a superficial examination reveals much of consequence.

In general it is manifest even to the casual observer that everywhere east of the Mississippi River the material composing the till is of northern origin. In Essex County Massachusetts, the bowlders are readily traced to localities in New Hampshire, some of them but a few miles away, and others from the White Mountain region, one hundred miles and more distant. My attention was early attracted throughout that region to bowlders of porphyritic gneiss containing very large and characteristic crystals of feldspar. The nearest ledges containing this class of rock are in the vicinity of Lake Winnipiseogee, in New Hampshire, seventy and more miles away, where the rock is a marked feature. So the whole mass of drift covering Plymouth County, Massachusetts, and that forming the hills of Cape Cod and of the islands to the south, is evidently of northern origin, and much of it from no great distance. Plymouth Rock is a boulder from the direction of Boston. Prof. N. S. Shaler is able to trace the bowlders removed from a small mountain in the north of Rhode Island, and to estimate their amount with such accuracy as approximately to determine the extent of erosion taking place under a movement extending from that point to the terminal moraine. The material occurs in a triangular-shaped area to the south with its apex at the mountain. (See his forthcoming report.) The bowlders scattered over the surface of the moraine in Long Island consist largely of granite, gneiss, hornblende rock, mica slate, and red sandstone, which are easily recognized as from well-known localities in Rhode Island, Connecticut, and Massachusetts.¹

Prof. Dana has also described many bowlders in the vicinity of New Haven which have been transported from well known trap-dikes, sixteen miles or more distant, and in a northeasterly direction. One

¹Natural History of New York, part 4, Geology, part 1, p. 165 et seq.



EXPOSURE OF TILL SOME MILES EAST OF LANE'S MILL SECTION.

these, called Judges' Cave,¹ on West Rock, 365 feet above the sea, must weigh a thousand tons.

A remarkable train of bowlders in Richmond, Massachusetts, near the summit of the Berkshire Hills and extending several miles was long ago described by President Hitchcock and Sir Charles Lyell, and more recently and accurately by Mr. E. R. Benton.²

In New Jersey, according to Prof. Cook, the bowlders are readily traced all along the morainic margin, as belonging to well known outcrops, of trap, blue limestone, and crystalline rocks to the northwest. Near Drakestown, in Morris County, there is a mass of blue limestone which had been worked for years as a quarry without suspecting that it was but a bowlder. "As exposed it measures thirty-six feet by thirty feet, and the quarrying has gone twenty feet in depth. Its vertical diameter is unknown. Around it there are many gneissic bowlders and other drift materials." This mass is about one thousand feet above sea level, and its native place must have been some miles to the north.

In Pennsylvania the distance from which the glacial material near the border of the glaciated region has been transported becomes at once more evident, because of its unlikeness to the local rocks. West of the Blue or Kittatinny Mountains there are no crystalline rocks in the State. Nor are there any such rocks to the north nearer than the Adirondacks in New York, or the highlands in northern Canada. Yet, granitic, gneissoid, and hornblendic bowlders abound all along the glaciated border, and are an important means of determining the glacial limit. In the valley between Blue Mountain and Pocono Mountain, Monroe County, and on the summit of the Pocono plateau, 2,000 feet above the sea, granitic bowlders from one to three feet in diameter are abundant, though mingled with great piles of local fragments. The granite must have been transported a distance of 250 miles at least, and carried over the summit of the Alleghanies lying to the northwest, and across the valley of the Mohawk in New York. The northern tributaries of the West Branch of the Susquehanna, likewise, bring down into that stream numerous granitic pebbles, showing that the glacial deposits in Lycoming County contain material from the far north which has been carried bodily over the summit of the Alleghanies. In proceeding west, the granitic mountains from which that material could come gradually recede to the north, thus increasing the distance between such bowlders and their possible original home. From Salamanca, New York, southwestward to Cincinnati, the whole country is literally covered, down to the glacial limit, with granitic, gneissoid, and hornblendic bowlders. Near Salamanca such bowlders abound at ele-

¹ See Am. Jour. Sci., 3d series, vol. 26, 1883, p. 347.

² Lyell's Antiquity of Man, pp. 355-362; Bull. Mus. Comp. Zool., Harvard Coll., vol. 5, no. 3, 42 pp. with map.

³ Geol. Survey New Jersey, annual report State geologist for 1880, p. 30.

vations not far from 1,900 feet above tide and 700 feet above the Alleghany River. In Beaver County they are numerous on the hills to within 6 or 7 miles of the Ohio River, and several hundred feet above it. In Columbiana County, Ohio, a granite boulder was found measuring 13 by 11 feet and 8 feet out of ground. Others were noted measuring 8 and 5 feet in diameter. In the same vicinity the till contains finely striated fragments of local sandstone, showing direct glacial action on the rocks of the vicinity. In Holmes County, mingled with fragments of granite in the till, were finely polished and striated pebbles of Corniferous limestone, which must have been brought from the other side of the water-shed, in the vicinity of Lake Erie, which is 100 miles distant. Near Lancaster, in Fairfield County, there is a granitic boulder measuring 18 by 11 by 6 feet out of ground. In Ross County, near Adelphi, Chillicothe, and Bainbridge, granitic boulders are found on the hills from four to six hundred feet above the valleys, that is, up to one thousand to twelve hundred feet above tide. A hornblendic boulder 5 by 3 by 2 was noted 550 feet above Bainbridge. In Brown and Clermont and Hamilton Counties granitic boulders abound on the hills down to the very edge of the trough of the Ohio. Here, also, are numerous boulders of jasper conglomerate from the region north of Lake Huron or near the lower end of Lake Superior. The variegated pebbles of red jasper and of darker quartzites form a striking feature in the rocks of that northern region. The boulders of this material found in the vicinity must have been transported nearly six hundred miles. Several boulders of this description, from two to three feet in diameter, were found in Boone County, Kentucky, a number of miles south of the Ohio River, and between five and six hundred feet above it. Boulders of this jasper conglomerate are very abundant in Michigan, are not infrequent in northern Ohio, and occur in various localities in southern Indiana—one being observed near Nashville, Brown County, Indiana, near the highest land in the State (about eleven hundred feet). Granitic and hornblendic boulders are very abundant in Illinois as far south as Carbondale, Jackson County, near latitude $37^{\circ} 35'$ north. The bed rock is also here distinctly striated, showing the transportation of boulders must have been independent of any stream of water. The distance from this point to the parent ledges can not be less than 600 miles to the north.

REGULARITY OF DISTRIBUTION OF TILL NEAR THE MARGIN.

(1) DISTRIBUTION OF THE TILL EAST OF THE ALLEGHANIES.

NEW ENGLAND.

Over New England the natural inequalities of the country are partly responsible for the irregular distribution of the till.¹

In New Hampshire the phenomenon of a sloping mass of till south of a ledge of rock is frequently to be noted. But, as if to check too hasty a generalization respecting the manner of their formation, it has

¹ Chapter by Warren Upham, *Geology of New Hampshire*, vol. 3, 1878, pp. 225-333.

so to be noted that in about one-third of the instances in which deposits of till slope up against a rocky eminence the till is on the northern slope in the direction from which the ice came. Moreover, these accumulations sometimes slope both ways, and what is more remarkable still, often surmount in symmetrical form low rocky elevations whose surface is finely polished and striated by glacial action. So often do these lenticular-shaped¹ masses of till surmount low rocky eminences that Prof. Shaler at one time endeavored to explain their origin on the theory that they were but the remnants of a deep ground moraine which had originally covered the whole surface, but, during a supposed depression of the country to the sea-level, had been eroded by the waves wherever they were not protected by the rocky elevations at their base.² But these lenticular hills, or drumlins, abound in certain portions of southeastern New England³ and in central New York south of Lake Ontario.

In southeastern New England these lenticular accumulations "vary in size from a few hundred feet to a third or a half mile in length, with usually about half or two-thirds as great width. Their height, corresponding to their area, varies from 40 or 50 feet to 150 or 200 feet. But whatever may be the size of these hills, they are singularly alike in outline and form, usually having steep sides, with gently sloping, rounded tops, and presenting a very smooth and regular contour."⁴

The prevailing direction of the longer axis of these hills is the same as that of the glacial striæ in their vicinity. In composition drumlins do not differ materially from the ordinary deposits of till in the same region. The material is for the most part unstratified, the clay is very compact; striated stones are commingled with the clay in every portion. There are, however, in these hills, as in the till as ordinarily arranged, occasional layers of stratified material, so that water for domestic purposes is usually found by sinking wells of no great depth. The boulders upon the surface of the lenticular hills are also both larger in size and more angular in shape than those in the lower part of the deposit. I have not observed anywhere in Ohio, Indiana or Illinois, any marked tendency of the till to assume this lenticular shape. Nor have I been able to detect any generic difference between the composition of these hills and the general deposit of till over the portion of these interior States which I have surveyed. At the same time, it is perhaps worthy of note that the total deposit in the interior States averages a much greater depth than in New England. In Ohio, as already remarked, a reasonable calculation makes the average depth

¹ Hence called by Prof. C. H. Hitchcock "lenticular hills," but Prof. Shaler thinks it best to retain the name "drumlins," given to similar accumulations in Ireland.

² See Proc. Boston Soc. Nat. Hist., vol. 13, pp. 196-203.

³ See Upham, Geol. New Hampshire, vol. 3, pp. 285-309; glacial drift in Boston and vicinity, Proc. Bost. Soc. Nat. Hist., vol. 20, pp. 220-234.

⁴ Upham, Geol. New Hampshire, vol. 3, p. 288.

of the till upwards of 56 feet, while in New Hampshire Mr. Upham estimates that the whole deposit if evenly spread out would not exceed an average of 10 feet. But Mr. Upham now informs me that he thinks his early estimate much too small. This difference may be accounted for in two ways: first, the rocks from which the till of New England is derived are mainly crystalline, and hence of firmer texture than those from which the material of the till near the margin of the glacial limit in the interior is derived. The sandstones, shales, and limestones of the interior would much more readily yield to the disintegrating influences of glacial action than the granite and gneiss of the east would do. In the second place, the depth of the deposit is ordinarily greater over the southern portion of the glaciated region than over the northern, so that the deposits in Massachusetts are noticeably greater than those in New Hampshire for which Mr. Upham made his calculations.

The region under my immediate investigation in the interior States perhaps corresponds, in its proximity to the glacial margin, more nearly with the southern portion of New England.

The extreme southern portion of New England and Long Island are characterized by massive and irregular deposits of glaciated material. The backbone of Cape Cod consists of a line of hills from one to three hundred feet in height and from one to three miles in breadth, flanked on the southern side by extensive deposits of water-worn material. In contour and composition these hills very much resemble the kettle moraine of Wisconsin as described by President Chamberlin. According to my own observation, however, the terminal deposits in southern New England are composed of less water-worn material and contain more striated stones than the corresponding formation in Wisconsin. But like the kettle moraine, this line of deposits on the southern border of New England, abounds in kettle-holes of all sizes and is composed of transported material loosely thrown together. That the deposit on Cape Cod is not truly terminal, however, appears from the fact that the islands to the south are composed of similar deposits. Nantucket, Martha's Vineyard, the Elizabeth Islands, and many smaller islands between, are but the summits of submerged morainic deposits of unknown depth.¹ Farther west this same line of morainic hills continues, appearing near Point Judith in Rhode Island, and running to Watch Hill, and thence through Plum Island and Fisher's Island to the north shore of Long Island as far west as Port Jefferson, where it disappears. The parallel lines of hills, after forming the irregular outline of No Man's Land, Block Island, and the eastern part of Long Island from Montauk Point westward to Sag Harbor and Roslyn, continues to be the chief feature of the country as far as Fort Hamilton and Staten Island, south of New York City.²

¹For description see Upham, *Geol. New Hampshire*, vol. 3, pp. 301-305, and B. F. Koons, *Am. Jour. Sci.*, 1884, 3d series, vol. 27, pp. 260-264; 3d series, vol. 29, 1885, pp. 480-486.

²See Upham, *Am. Jour. Sci.*, 3d series, vol. 18, pp. 86, 198.

NEW JERSEY.

Across New Jersey the accumulation of loose and glaciated material brought from the north is well marked down to the very margin of any signs of glaciation whatever. But the terminal deposit is not relatively so excessive as along the region eastward through Long Island and Cape Cod. On crossing the Delaware River at Belvidere, and throughout the whole region westward, the relative inferiority of the extreme marginal deposit is still more marked, except in a few localities, which may best be mentioned in this connection.

PENNSYLVANIA.

In *Northampton County, Pennsylvania*, just west of the Delaware River, the character and extent of the glacial deposit continues very much as in New Jersey. Near Middagh's, the most southern point of glacial signs in the county, the deposit is certainly as much as fifty feet in depth, and is, without question, till. This is about six miles east of the river, and is 625 feet above it. Nearer the mountain, not far from Bangor, the marginal deposit is, even at a still greater elevation, from one to two hundred feet in thickness, and for a mile or more is dotted with kettle-holes.

Monroe County spans a section east and west from the summit of the Blue Mountains to the summit of Pocono Mountain and the western border of the Pocono plateau looking towards the Lehigh River, a distance of 30 miles. The elevation of the Blue Mountains is in round numbers 1,400 feet above tide; that of the Pocono plateau, 2,000 feet. The valley between them is about eight miles wide, and is but 620 feet above tide. At Saylorsburgh, in the middle of this valley, there are extensive kettle-holes, and the deposit of till is very deep (Prof. Lewis estimates it as "several hundred feet") and covered with large boulders, some of which are from the Adirondacks, 250 miles away. Five or six miles away, on the summit of the Pocono plateau, 1,400 feet higher, the marginal deposit is equally remarkable. For many miles in width a level, sandy plain extends in all directions. The soil over that portion of it situated south of the glaciated region is thin; being composed simply of the superficial disintegration of the compact Pocono sandstone. Upon going north in Tunkhannock township, one suddenly strikes into a glacial accumulation (near the boundary of Lobyhanna township), which is remarkable at once for its length, its height, its composition, and the abruptness of its southern margin. For a distance of about twelve miles the accumulation forms a marked feature of the landscape, and is known in the locality as "Long Ridge." This is truly morainic in character, is one hundred feet or more high, consists of a confused collection of boulders (some of granitic character from the far north), and incloses near its margin numerous small lakes which have no outlet. These are neither more nor less than kettle-holes, and they are specially remarkable from the fact that some of

them are near the eastern margin of the plateau, which here forms an escarpment of several hundred feet. A little farther west this moraine so obstructs the outlets of several small streams flowing northward as to form small lakes to the south of it.¹

Luzerne County.—It is unnecessary to do more than merely mention a few other places in Pennsylvania where the abruptness and amount of the terminal accumulations are noteworthy. But it may be well to note that upon the western flanks of the mountain in Luzerne County, between the Lehigh and the Susquehanna Rivers, the southern-margin of glacial action is very sharply defined, so that, according to Prof. Lewis,² the southern limit of the glacier can be determined to within a few yards. The accumulations in the valley of the North Branch of the Susquehanna, above Beach Haven, are also very large, and are unquestionably a direct glacial deposit, as can be seen to good effect by comparing them with the material near the river, at and below the intersection of the glacial border, where extensive terraces, 75 feet high, line the stream for one-fourth a mile on either side. Beach Haven is but 530 feet above tide.

Columbia County.—Another striking mass of glaciated material in the same vicinity occurs in Sugarloaf township, Columbia County. This is in the valley of Fishing Creek, west of Shackshinny Mountain. The valley is filled from side to side with a heterogeneous collection of large sandstone and conglomerate bowlders (some of them six feet in diameter), mingled with unstratified finer material, and to a depth of seventy-five feet or more. This deposit extends several miles south on the east side of the valley, but is entirely absent south of this point on the western side. The elevation of the valley is about one thousand feet above tide. The Alleghany Mountain rises 1,100 feet higher four miles to the north. This is but four or five miles south of the striæ on the summit of the mountain, mentioned on p. 40. A few miles west of this point the signs of glaciation cease.

Lycoming County.—On the summit of the Alleghany Range, near Ralston, in Lycoming County, the deposits are thick on the highlands east of Lycoming Creek, and about eight hundred or one thousand feet above it. But the narrow valley itself contains nothing but water-worn material, both to the south and for several miles to the north of Ralston.

NEW YORK.

In Cattaraugus County, New York, the terminal deposits are specially abundant in the township of Great Valley south of Ellicottsville and upon the hills south of Randolph. Great Valley, just south of the village of Peth, is filled with till from side to side (about one-eighth of a mile) to a depth of at least 60 feet and for a long distance. Scratched fragments and pebbles of granite and gneiss are abundant in the de-

¹ Second Geol. Survey Pennsylvania, Z, pp. 74-78.

² Ibid, p. 103.

sit at this point and to the north, but to the south there is nothing in the valley except water-worn material arranged in regular terraces. At Cambridge, about 20 miles further west, in the old valley east of Randolph, wells penetrate the stratified gravel 70 feet without reaching rock, and probably would have to go much deeper to reach it. This was probably, according to Prof. Carll,¹ the preglacial outlet of the Upper Alleghany River, which is known not to have flowed at that time south of Warren, Pennsylvania, since its upper and buried channel is much higher than that below Warren.

(2) DISTRIBUTION OF THE TILL WEST OF THE ALLEGHANIES.

GENERAL REMARKS.

In considering the glacial deposits of western Pennsylvania and of northern and southern Ohio it is important to bear in mind the ordinary topography of the country above tide and its preglacial condition. From Albany, New York, to Cincinnati, Ohio (a distance in a straight line about 380 miles), the general course of the glacial boundary is south-west, and is approximately parallel with the axis of the Appalachian mountains, and continues throughout not far from the northwest outcrop of the Appalachian coal-fields, being inside the line of outcrop as far as Knox County, Ohio, and from thence to the Ohio River in Brown County, passing over a country characterized by extensive outcrops of heavily sandstone. Over all this region preglacial erosion had been very extensive, as is evident to a superficial observer, from the long, deep channels cut by all the streams through the coal measures outside the glacial limit, and where there has been little to disguise the effect of a long-continued erosion. The Ohio River, from Louisville, Kentucky, to Pittsburgh, Pennsylvania, occupies a valley of erosion averaging about a mile in width, and bordered on each side by parallel horizontal strata of rock rising in nearly perpendicular bluffs from three to five hundred feet in height. The same trough continues in similar proportions up the Alleghany River to near its source, except that it is narrower and in its upper portions deeper. Furthermore, deep as is this valley, there is abundant evidence that before the glacial period it was still deeper, it having been filled up, as estimated by Newberry,² more than one hundred and fifty feet by a postglacial river deposit. For example, at Cincinnati the gravel and sand have been repeatedly penetrated to a depth of more than one hundred feet below the bottom of the river without reaching the rock. At New Philadelphia, Tuscarawas County, Ohio, borings show that the old bottom of the Tuscarawas River was 175 feet below its present depth. Near New Castle, Pennsylvania, the bottom of the old trough of Beaver Creek is shown to be 150 feet below the present bottom.

¹ Second Geol. Survey Pennsylvania, III, pp. 330-439.

² Geol. Survey, Ohio, vol. 2, pp. 1-80.

In the same manner all the streams tributary to the Ohio occupy narrow, deep valleys of erosion, entirely devoid of waterfalls, showing that in all cases they have been at work in their present valleys from the very earliest times. The difference between the elevation of the country about Salamanca and that at Cincinnati corresponds very nearly with the fall of the Alleghany and the Ohio Rivers between those points. The Alleghany River at Salamanca is 1,360 feet above tide. The country to the north and west is about 1,900 feet above tide. The Ohio River at Cincinnati is 447 feet above tide. The elevation of the surrounding country is between nine hundred and one thousand feet above tide. North of the glacial limit there is every reason to suppose that preglacial erosion had produced effects corresponding to what is now visible throughout southeastern Ohio, southwestern Pennsylvania, and West Virginia. But to a great extent these preglacial channels have been completely filled up with till, so as to make important changes in the line of drainage and to give an entirely different aspect to the whole glaciated region from that borne by the country outside of the limit. Indeed, as remarked above, the glacial boundary throughout southwestern Ohio and the whole of Indiana and Illinois corresponds very closely with the boundary of the prairie region in those States, so that the natural scenery, the character of the soil, the water supply, and nearly all the elements determining the vast agricultural interests of those States have been produced by the ice movement during the glacial period. The till which is spread over this area represents what Newberry calls "the grist" of the continental glacier, and altogether constitutes an immense mass, amounting in Ohio alone to a stratum averaging more than sixty feet in depth over about twenty-five thousand square miles. As compared with the deposits in New England, this is so nearly uniform in its deposition that it has been beyond my power, if not my province, to trace any extensive system in the irregularities which appear. The results of the attempt to trace such a system are given by President Chamberlin.¹ I will content myself with briefly indicating the approximate amount of deposition along a belt from ten to twenty miles wide, forming the southern and eastern margin from Salamanca, New York, to the Mississippi River, taking the counties in order.

PENNSYLVANIA.

Warren County.—In the Conewango Valley above Warren, in Warren County, the glacial accumulations are very marked, filling it from side to side, forming a well-defined ridge rising abruptly about seventy feet on its northern side, near Ackley Station. For about two miles the material of this deposit is clearly till, but it gradually changes into water-worn material, which is spread along the margin of the stream as a regular terrace. This morainic deposit rises diagonally upon the flanks of the

¹ Preliminary paper on the terminal moraine of the second glacial epoch, Third Annual Report U. S. Geological Survey, pp. 330-335, 339, 341.

hill to the east for a long distance and to a height of several hundred feet. Upon the west side of the valley the glacial deposits are deep all over the northern tier of townships from Pine Grove westward, and they appear as if pushed up to the watershed between Lake Erie and the Alleghany, which is here 1,900 feet above the sea, more than 1,200 above the lake, and about 700 above the Alleghany.

The till in many places is certainly twenty-five feet in depth, and extends in a continuous sheet northward as far as Jamestown, New York. It is pushed far up upon the northern slope of Pike's Ridge, in Sugar Grove township, Pennsylvania, to a height of about four hundred feet above the country to the north. In the southwest part of the county granitic boulders and striated stones are numerous upon the high land in the southern part of Deerfield township. This is several miles nearer the Alleghany River than the line as determined by Prof. Lewis and myself in 1881 for the Pennsylvania Survey.

Venango County contains a glacial deposit of considerable depth near its western border; but the deep accumulations are for the most part in the valleys now occupied by streams. Here also, as in Warren County, the glacial limit must be put several miles nearer the Alleghany River than as delineated by Prof. Lewis and myself in 1881. Granitic boulders and striated pebbles abound in Cherry Tree, Oakland, Sugar Creek, and Sandy Creek townships, at an elevation of about six hundred feet above the river and about one thousand seven hundred feet above tide.

Crawford County lies wholly within the glacial limit, and with the exception of its southeastern portion is uniformly and deeply covered with till.

Mercer County also lies wholly within the glaciated area, and is deeply covered with till, except upon its higher summits, which contain numerous glacial striæ.

Butler County.—The glacial limit barely grazes the northwestern portion of Butler County, passing through Mercer, Slippery Rock, and Worth townships. Granitic boulders are numerous down to very near the margin.

Lawrence County is completely enveloped in till, with the exception of the two southeast townships. The depth of the till, even upon the higher lands, as at Mount Jackson, certainly approaches 50 feet.

Beaver County.—Till is pretty deep over the extreme northwestern part of Beaver County, in Darlington township. Boulders and thin deposits of till are found upon the highlands ten miles farther south, to within about ten miles of the Ohio River, but none could be found upon the high land beyond those points. The boulders found in the terraces at the mouth of Beaver Creek were transported down the stream by water.

OHIO.

Columbiana County.—The northern half of Columbiana County is deeply covered with till, while it is entirely absent in the southern half.

Within two miles of the southern boundary of the deposit, in the most western township, the till is thrown up into hummocks, and incloses kettle-holes of moderate size upon the highest land, constituting at that point the water-shed between the Mahoning and the Tuscarawas rivers. Wells are reported as penetrating the till 50 feet without reaching rock. Throughout the country, especially in the eastern part, granitic boulders are found upon the high lands along a belt four or five miles south of the deeper deposit.

Stark County is deeply enveloped in till all over its northern and western half, while the southeastern part is completely devoid of glacial marks. Two or three miles west of Canton there is a remarkable series of ridges and kettle-holes, ending in Buck Ridge, which rises 85 feet out of an extensive gravel plain, with a base of 570 feet, and ascending from the east side with a slope from 18° to 25° . This kame—for so it properly is—is coarsely stratified, and contains many granitic pebbles and boulders. One boulder, about the middle of a cross-section half way up, measured nearly five feet in diameter. To the north the ridge continues to an indefinite distance, inclosing large kettle-holes. One of these was 300 feet long and 40 feet deep, with the bifurcated edges of the ridge as its rim. This seems to be the southern extension of the large kame-like deposits which abound between Akron and Ravenna, upon the watershed between the Cuyahoga and the Nimishillin, about twenty-five miles to the north. The numerous lakes throughout that region are all “kettle-holes.” The extreme southwestern part of Stark County is deeply covered with till, and there is an immense kame like accumulation near the Tuscarawas River, and rising 154 feet above it, in the southern part of Bethlehem township.

Holmes County.—The northern half of Holmes County is deeply covered with till, while it is completely absent in the southern half, and the line is very sharply defined. The Killbuck River divides the county into two equal portions east and west, occupying a valley about a mile in width, and about 500 feet below the general level. The southern half of the county is very much broken, being everywhere cut up into deep gorges by the streams. Throughout the northern half, these gorges have been entirely obliterated by the glacial deposits. Deposits of till from twenty-five to thirty feet in depth appear at numerous places near the highest land in the county. In a broad place where these small streams unite in the valley, five miles north of Millersburgh, is a kame-like accumulation rising 125 feet above the stream, containing scratched stones. Near Millersburgh a cut in the till showed a very fresh appearance 20 feet below the surface, there being no signs of oxidation at that depth. There are extensive terraces on the Killbuck River near Killbuck post-office, rising 120 feet above the river.

Knox County.—All but the extreme eastern portion of Knox County is deeply enveloped in till. The glacial boundary is here running a few degrees west of south. At Danville, wells were reported penetrating

126 feet (probably in a preglacial channel) through yellow clay, blue clay, gravel, quicksand, and cemented gravel without reaching rock. The railroad cut shows glacial material from twenty-five to forty feet deep for a distance of about 400 yards. This is on the extreme eastern limit of the glacial area.

Licking County is enveloped with till to a depth of fifteen to thirty feet west of the two eastern tiers of townships, and the fringe of scattered glacial deposits outside is narrow.

Perry County lies wholly outside of the glacial region, with the exception of the northwestern township, where, at Thornville, the glacial deposit upon the hills south of the old reservoir is certainly 35 feet in depth. Large boulders are numerous.

Fairfield County is deeply covered with till, with the exception of its three or four southeast townships, which in places very near the margin is certainly 40 feet in depth at an elevation of 450 feet above the canal at Lancaster.

Ross County.—The glacial limit passes through Ross County diagonally from northeast to southwest. The accumulations at Adelphi, in the extreme northeast corner of the county, in the valley of Salt Creek, are in general very fresh in appearance and show an exposure of 188 feet. The same formation rises to 200 feet a mile or two west. A few scattered pebbles of granite were found three or four miles outside of this limit upon hills 400 feet above Salt Creek, and glacial accumulations are continuous in the Scioto Valley to Circleville. In Green township, in the eastern part of the Scioto Valley, there are immense kame-like ridges of gravel largely composed of limestone fragments, rising 150 feet (barometer) above the plain. Near Lattas P. O., in Twin township—550 feet (barometer) above the Scioto Valley at Chillicothe—a well upon the farm of J. McConnell penetrated till 31 feet (12 feet yellow clay, 4 feet blue clay, 10 feet yellow clay, 5 feet gravel). Three miles north of this is a broad valley 400 feet lower. Wood was found in this well in the clay 13 feet from the surface. Scattered glacial deposits upon the summit are found three or four miles farther south; but the deposit continues at a great depth to the west as far as Highland County.¹

Highland County is completely enveloped in till, with the exception of its southeast corner. Over the northern and western half the deposit is deep, but rather thin southeast of Hillsborough. A mile or two south of Hillsborough there is an extensive deposit, about 40 feet thick, of cemented gravel containing granitic pebbles, having nearly the elevation of Hillsborough itself, which is 500 feet above Chillicothe, and 700 feet above low water at Cincinnati, 1,135 above tide.

Brown and Clermont Counties are deeply covered with till over their northern portion, and glacial deposits are more or less marked down to the Ohio River as far east as Eagle Creek, Brown County. In the south-

¹ For farther particulars concerning the deposits in this county along Paint Creek see p. 53.

ern part of these counties the till is pretty generally of a reddish color, showing thorough oxidation. Lewis and Pleasant townships, in Brown County, on the Ohio River, abound in these deposits of till down to the very margin of the trough of the Ohio, where the general level is from 400 to 450 feet above the river. Numerous deposits within a mile of the escarpment were noted from ten to twenty feet in depth, and contained granite boulders three or four feet in diameter.

Nearly the entire water-shed, many miles in width, east and south of the East Fork of the Little Miami, and occupying and covering the western part of Highland, the northern part of Brown, and the southern part of Clermont County, and lying from 400 to 500 feet above the Ohio River, is covered by a level and uniform deposit of loamy soil, fine and light colored at the top, with gravel toward the bottom from three to seven feet deep. Granite is a frequent constituent of the gravel, the surface is a dead level, and the land is difficult to drain. The deposit is similar in every essential respect to those afterward to be described in the southeastern counties of Indiana and over a large part of the southern portion of the glaciated region in Illinois. The fine deposit at the surface is in these counties thin, being scarcely ever more than two or three feet in thickness, and resembles in composition the upper part of the loess appearing so extensively in Illinois and farther west.

Hamilton County.—Clearly marked glacial deposits are by no means continuous over Hamilton County, but they are scattered over it in a somewhat perplexing manner. In Anderson township, in the southeastern corner of the county, upon the Ohio River, much of the elevated portion of the country (375 feet above the river) is covered with till from 15 to 20 feet in depth, and granitic boulders are abundant. In the southern sections of Columbia township, cuts in till are frequent from 30 to 40 feet in depth. At Avondale and Walnut Hills, in the upper part of the city of Cincinnati (from 250 to 350 feet above low-water mark), cuts in till from fifteen to twenty feet in depth are exposed. In this there is no appearance of stratification; granitic fragments up to 20 inches in diameter are abundant, and in general are not water-worn; striated fragments of local rock and Corniferous limestone from the northern part of the State are also abundant. Upon the western side of Mill Creek no distinct deposits of till could be found upon the highlands in the townships bordering the Ohio, nor in Green township, still farther to the north. The region, however, is covered pretty generally with a deposit from six to ten feet in depth, consisting of fine clay, of a whitish yellow for the first three or four feet from the surface and a reddish color below, with some gravel near the bottom, and occasionally a striated pebble. The general elevation above the river is not far from 400 feet. At North Bend, in Miami township, a preglacial valley, formerly connecting the Big Miami with the Ohio, is filled with till to a height of 160 feet above the river. Striated pebbles in this are numerous. Colerain and Springfield townships, in the northern part of the county,

are, over their southern portions, pretty generally covered with from ten to fifteen feet of clay comparatively free from pebbles; but in their northern part, near Pleasant Run, deposits of true till are deep and abundant.

Butler County, to the north of Hamilton County, is everywhere deeply enveloped in till, fresh sections of which, near the city of Hamilton, contain undecayed specimens of wood, and show as little signs of oxidation as anything in the northern part of the State.¹

KENTUCKY.

Campbell, Kenton, and Boone Counties form a sort of promontory looking towards the north, with the Ohio River on the east, north, and west sides. Since the direct glacial deposits come down to the river banks in Clermont and Brown Counties on the east in Ohio, and in Dearborn, Ohio, Jefferson, and Clarke Counties in Indiana, it becomes of special interest to note the facts over the intervening portion of Kentucky with care.

Campbell County.—The hills in Carthage precinct facing the river to the east and opposite New Richmond, Ohio, about twenty-five miles above Cincinnati, are enveloped with a deposit of till from ten to fifteen feet in depth in which granitic boulders are numerous. This extends to an elevation of from 350 to 400 feet above the river opposite New Richmond, but none could be found upon the hills in the southern part of the precinct. Nor could any till or granite pebbles be found upon the summit between the Ohio and Licking Rivers in this county from Alexandria to Dayton (the general level being about 400 feet above the river). The soil, from six to ten feet deep, is clay, being yellow near the surface, but dark gray below. A deposit of sand near Alexandria upon the summit is a decomposed remnant of sandstone.

Kenton County.—A détour from Visalia northwest towards Florence (over elevations ranging from three hundred and fifty to five hundred feet above the river) discloses no glacial signs until reaching the Boone County line, three miles southeast of Florence. Here seven miles south of the Ohio, there suddenly appears a stiff clay deposit containing numerous granitic pebbles three or four inches through (see specimens 91 and 92). From this point northward towards Florence granitic boulders abound. Five were measured which were each upward of two feet in diameter. The covering of the soil was only from two to three feet (the elevation is about five hundred feet above the Ohio).

North of this, a railroad cut at Erlanger (475 feet above low-water mark in the river), shows clay six feet, containing small pebbles of quartzite, limestone and granite.

From Erlanger to Covington a deep deposit (from twenty to twenty-five feet) of loess merging into loam, with some gravel at the bottom, everywhere appears along the road.

¹ See p. 49.

Boone County.—One and a half miles southwest of Florence a boulder of jasper conglomerate, three and a half feet in diameter was found in the headwaters of a small stream emptying into Gunpowder Creek (elevation about five hundred feet above the river at Cincinnati). Two miles west of Florence there are other boulders of this jasper conglomerate with thirty or forty granitic boulders, many of them two or more feet in diameter. These also are in a branch of Gunpowder Creek and 500 feet above Cincinnati. This conglomerate is identical in composition with that found in place on the south shore of Lake Superior and to the north of Lake Huron, the boulders from which are widely scattered over Michigan, Indiana, and northern Ohio.

One mile east of Hebron there is a deposit of till 12 feet or more in depth, and 450 feet above the river. The whole surface of the country about Hebron is covered with a loamy deposit containing occasional scratched stones and pebbles.

From Petersburg to Big Stone Lick the summits of the bluff, up to about 450 feet, and perhaps higher, are enveloped with a loam containing numerous granitic and other pebbles. There is no appearance of stratification. Near the headwaters of Middle Creek, at an elevation of 300 feet above the river, six miles southeast of Petersburg and three miles east of Bellevue (Grant post-office), the washed pebbles of this gravel are cemented together by an infiltration of lime, forming perpendicular exposures of 50 feet, where cut through by the streams. The pebbles are mostly lime rock of the Cincinnati series, but some, a foot or more in diameter, are granitic.

An extensive deposit of this loam appears on the highlands south of Gunpowder Creek, two miles northeast of Big Bone Lick, by Big Bone Baptist Church, near the junction of Hamilton and Union precincts, 500 feet (barometer) above the river.

A section made still farther south, from Glencoe to Warsaw, in Gallatin County, failed to disclose similar deposits there.

Similar to the conglomerate at the headwaters of Middle Creek is that facing the river at the mouth of Woolper Creek, known as Split Rock (see plates III and IV), which show the cliffs of conglomerate across the creek from Split Rock.

The pebbles in the cemented masses are mostly of limestone, and are very coarse, individual pebbles frequently being from three to four feet in diameter. Granitic pebbles are infrequent. One was found, however, measuring two feet in diameter. The cliffs of this conglomerate, at the mouth of Woolper Creek, rise 185 feet above low water, and the material is cemented together by an infiltration of lime. Kamelike ridges extend for two miles south of Woolper Creek, on the way to Bellevue. These are composed of rather fine material, and are 160 feet above the river. The terrace upon this, the Kentucky side of the river, for two miles or more below Woolper Creek, is remarkable for its height, being more than 100 feet above the river, and 56 feet higher than the high-water mark of January, 1883.



CLIFF OF POST-GLACIAL CONGLOMERATE SOUTH OF WOOLPER CREEK, NEAR SPLIT ROCK, KENTUCKY.

Trimble County.—South of Madison, Indiana, on the opposite side of the river, in Kentucky, the level-topped table-land (450 feet, barometer, above the river) is covered for several miles with a yellowish loam or silt, two to five feet, graduating into a stratum containing a large number of flint chips, but no granitic pebbles. There were, however, some quartzite and compact red sandstone pebbles, giving some signs of glaciation; also near the river a few granitic pebbles were found 440 feet (barometer) above the river.

INDIANA.

In Indiana the glacial boundary line still continues to bear in a westerly direction through Ohio, Switzerland, and Jefferson Counties, crossing the edge of Kentucky again opposite Madison, and reaching its southernmost point near Charlestown, in Clark County.

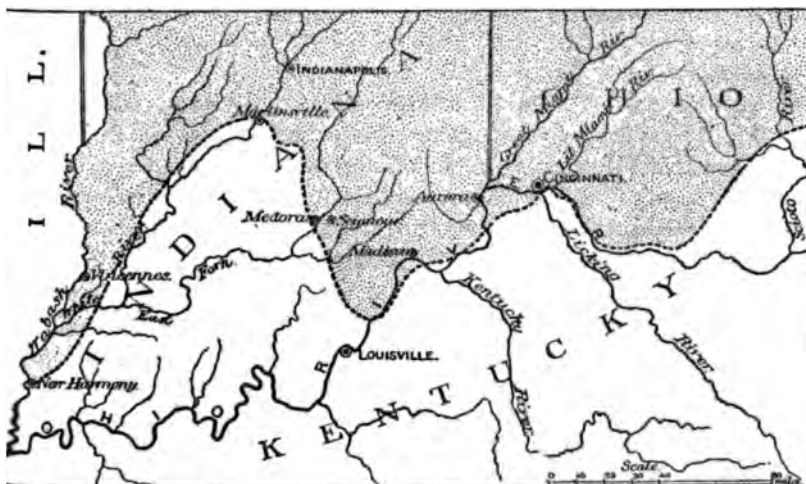


FIG. 2.—Map of southern Indiana, showing glacial boundary.

From here it bears again to the north through Scott and Jackson Counties to the line between Bartholomew and Brown, and follows this to the northeastern corner of Brown. There again it turns to the southwest, touching the northeast corner of Monroe, where it again bears north for 10 miles, to near Martinsville, Morgan County. Here the line turns west and south, passing diagonally through Owen, Greene, Knox, and Gibson Counties, and into Posey County to New Harmony.

Dearborn County.—At the Junction of the Miami and the Ohio, just above Lawrenceburgh, the valley is between two and three miles wide, and the level-topped highlands on the west rise to an elevation of 500 feet. Thin deposits of till were found upon these highlands with scattered granitic bowlders over the whole southern part of the county. The interval upon the Ohio is here bordered on the west by a stratified terrace of water-worn material from one-fourth to one-half mile wide, 80 feet above high-water mark, largely composed of pebbles two or three inches

in diameter. Opposite Lawrenceburgh remnants of this appear on the Kentucky side, and it continues at a similar height on the east bank for some distance up the Miami, in Ohio.

Ohio County.—At Hartford, Ohio County, south of Laughery Creek, a deposit of clay, gravel, and small granitic pebbles (thrown up into small ridges and knolls) rises upon the north slope of the plateau to a height of 250 feet. Gold is found in this deposit. Upon the table-land 450 feet above the river, granitic boulders, from two to three feet in diameter, occasionally occur.

Switzerland County.—Upon the highlands, one-half mile back from the river, at Florence, York township (elevation 350 feet above the river), there is no appearance of glaciation, the clays being all residuary. An extensive terrace on the east side of the river is 100 feet above low-water mark. The highlands in Jefferson and Craig townships, northwest of Vevay (475 feet above low water), are covered with a deposit of reddish clay, from two to three feet thick, abounding in granitic pebbles.

Jefferson County.—On the edge of the level-topped highlands, at North Madison, 475 feet above low-water mark, there is a deposit of clay 20 feet deep, light yellow for a few feet below the surface, then reddish in color, with much flint and many small pebbles, some of which are of granite and are striated, especially through the lower half of the deposit. The fine material gradually merges into the coarse, and there is no stratification. The flint comes from the decomposition of limestones in the region further north. Detours made from here (30 miles north to Osgood, Ripley County; 25 miles northwest to Vernon, Jennings County, and 15 miles west-northwest to Paris, Jennings County) show that the whole table-land is covered with a formation similar to that described. This is of varying degrees of thickness, being sometimes 30 feet and more in depth on the highland. Granitic boulders and striated stone pebbles are abundant, but there are no knobs or ridges of drift.

Hanover and Saluda townships are of the same elevation and present the same features with the region north of Madison. Granitic boulders are abundant on the surface, sometimes two or three feet in diameter, and the till is occasionally from twenty to thirty feet deep upon the highlands, with granitic boulders near the bottom.

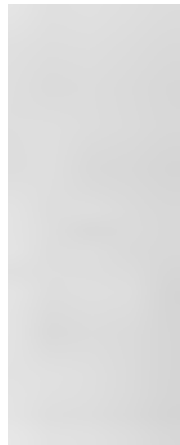
Ripley County.—At Milan (about five hundred and fifty feet above the river at Aurora), a well, according to Prof. Borden¹, gives the following section:

	Feet
1. Light-colored clay soil.....	10 to 14
2. Yellow clay, with flint, gravel, and fossil-corals.....	12
3. Blue glacial clay	12
4. Coarse, yellow sand, with recent shells and water	8
5. Blue clay, muck, containing roots and limbs of trees.....	6
Total	54

¹ Seventh Annual Report, Geol. Survey, Indiana, for 1875 (1876), p. 196.



A NEAR VIEW OF CLIFF OF POST-GLACIAL CONGLOMERATE SHOWN IN PLATE III.



ings County.—In Bigger township, in the southeastern corner of gs County, wood was reported from two wells in hard blue clay, 30 feet below the surface.

Borden reports the following section¹ from a well at Paris g:

	Feet.
-colored clay, with deeper shades below	10
-colored clay, with tint pebbles, increasing in hardness towards the tom	19
hard bed clay and gravel.....	2 to 3
drift clay, very sandy, with water; also limbs, twigs, and roots of s, continued to the depth of	7 to 10

t County.—Through Washington, Bethlehem, and Owens town- the characteristics described in Jefferson County continue. striated granite boulders, three to four feet through, abound Bethlehem, about half way up to the summit from the river. ill appears as far south as Charlestown; but thence to Jeffer- e, and turning northwest across the northeastern corner of County to Wood Township, Clark County, and thence on north- brough Washington and Lawrence Counties, no till or trans- boulders are to be found. Glacial deposits are found only on ng east to Brownstown, Jackson County. A prominent feature country from the eastern part of Floyd County to the north- part of Brown County are the knobs of Waverly sandstone, several hundred feet above the surface to the east, and dipping westward so as to underlie the coal which is in the western part State, corresponding to similar formations dipping in the opposite on in the Scioto Valley of Ohio.

County and the southeastern part of Jackson I have not exam- at have assumed that the limit lies east of the knobs just named. *son County.*—Till with granitic pebbles and striated stones was two miles southeast of Brownstown, bordering the sandstone

North of Brownstown, six miles across the intervale between st Fork of White River and White Creek, till rises about fifty m the plain against the foot hills. But the highlands in Salt township show no glacial deposits.

holomew County.—In the southwestern corner of Bartholomew till, abounding in granitic pebbles and striated stones, runs up highlands to within about two hundred feet of the summit of id hills; but it is absent from the southeastern corner of Brown r. Sections in Ohio township show it to be at least forty feet in and it continues, like a flat-topped terrace, eastward toward the rk of White River. Harrison and Union townships are covered ll from the east to within about two miles of the Brown County here it ceases upon the flanks of the sandy knobs, at a height of two hundred feet above the valley. Sections show this to be at ity feet deep.

¹Seventh Annual Report, Geol. Survey, Indiana, for 1875 (1876), p. 172.

Decatur County, to the east, is completely enveloped in till, but neither in that county nor in any south of it was my own attention called to anything like moraine hills, such as were described in the Eastern States, though I drove from Clarksburgh, in the northeastern corner of the county, to Greensburgh, and thence south through Osgood, Ripley County, to the Ohio.

Johnson County.—The southern part of Johnson County is completely enveloped in till, the deposits being sometimes ninety feet and more in depth.

Brown County.—The sandy knobs stretching northward from Floyd County, attain in Brown County, south of Nashville an elevation of 1,147 feet above tide. No glacial deposits were found upon these knobs along the eastern border of the county until reaching the extreme northeastern corner.

Till continues from Johnson County into the northeastern part of Hamblin township, Brown County, and rises to within about three hundred feet of the summit of the knobs. There are no granitic boulders in the beds of the streams running east from the knobs, but many very large ones are found near the glacial margin, one being five feet in diameter. Gold is also found here, as in Ohio County.

The northwestern part of Hamblin township and the northern part of Jackson township are covered with deep deposits of till, being fifteen or twenty feet deep at Georgetown, and rising to an elevation of 200 feet above Bean Blossom Creek. In the valley of Big Salt Creek, at Nashville, there is no till; but a few granitic pebbles and boulders are to be found. Northwest from Nashville, near the water-shed between Big Salt and Bean Blossom Creeks, and on the south slope, boulders of granite and jasper conglomerate, from three to five feet through, were found. Till also was encountered at Needmore, Jackson township.

Monroe County is wholly free from any glacial deposit, except in the extreme northeast corner.

Morgan County.—Jackson township is completely enveloped in till, often from thirty to forty feet in depth. At Morgantown, wood is reported as found in a well one-fourth mile from the creek, 30 feet below the surface. At Mahalasville, the glacial deposit terminates on the northeastern side of the valley of Big Indian Creek, in kame-like hills 107 feet high. The gravel in this hill is mostly fine, but contains boulders of decaying granite, two and a half feet, at different elevations. The valley of White River at Martinsville, Washington township, is about one and one-fourth miles wide, consisting mostly of intervale. Till appears on hills east of Martinsville, but there is none southwest.

Jefferson township is covered with deep deposits of till to about one mile south of its center, where it suddenly ceases.

Ray township contains glacial material only in its extreme northern part,

nam County is completely enveloped in till.

n County.—In Owen County the glacial line turns again to the west, running through Harrison, Taylor, Montgomery, Morgan, ette, and Jefferson townships.

the southeastern part of Harrison township is unglaciated; but glacial deposits are continuous over the northern part of the township.

Montgomery township till and bowlders in moderate amount appear to the F6, and are continuous north ten miles to Cloverdale.

the, with abundant granitic bowlders, also covers the highest hills in the northeastern corner of Morgan township, and three miles to the west.

Lafayette township the deposits of till are thin, but extensive throughout the northwestern half. Three miles south-southwest of Ellettsburg, striae were found running up hill nearly east and west in the capping sandstone strata. Five miles to the west, in Marion township, well-defined striae were found running S. 40° to 50° E.

the appeared in the northeastern corner of Jefferson township, and three miles to the southwest; but there was none in Franklin township.

ene County.—From Switz City, westward, no glacial deposits are seen for four miles; but they begin to be seen in Stockton township, where they are continuous to the western border of the county, being from one to twenty feet in depth. Scratched pebbles and granitic bowlders are abundant.

ivan County is completely enveloped in till.

x County.—East of Vincennes, on rising from the broad gravel bar of the Wabash, and one and a half miles from it, sand-hills rise one hundred feet. A mile farther on, hills rising one hundred feet are covered with loess, which completely envelops everything. In Harrison township, seven miles southeast from Vincennes, cuts ten or twenty feet through the loess revealed an irregular deposit of glacial till. The hills are here from one hundred to one hundred and fifty feet above the valleys, but the depth of the till could not be ascertained.

ness County.—Nothing like till was found in the southern part of Adams County in a drive from Washington to Petersburg, Pike Township.

son County.—At Princeton, Patoka township, there is a deposit of till thirty or forty feet deep, with granitic pebbles, one of which was found one and a half miles through. There were also numbers of striated pebbles on the bank. Loess, ten or twenty feet deep, covers rounded slate hills to the east. No granite pebbles were to be found in the eastern part of Princeton township and the western part of Columbia.

Owensville, Montgomery township, loess is everywhere on the surface, with blue till underneath containing granitic and scratched pebbles. Till also appears at Fort Branch, in the southern part of

Patoka township. Wells are reported as penetrating red and blue clay 20 feet. Eastward to Barton township no glacial material could be found.

Vanderburgh County.—Extensive detours in Vanderburgh County disclosed everywhere the loess resting upon the rocks in place, and the streams utterly devoid of gravel.

Posey County.—Robb township, in its eastern part, is so deeply enveloped in loess that the character beneath could not be determined. The hills are about two hundred feet above the Wabash (estimated). In the northwestern corner of the township, facing the valley of Black Creek the loess is underlaid by till, which is certainly 20 feet deep. Scratched stones and granitic boulders were numerous. This exposure continues for a mile and a half. Black Creek, which flows through this deposit, contains much granitic gravel. Granitic pebbles and striated stones occur also on the hills between Black Creek and the Wabash.

One-half mile southeast of New Harmony a section shows 15 feet of loess overlying till of an unknown depth, but with no sharp line of demarcation between them. The trough of the Wabash is here about five miles wide.

ILLINOIS.

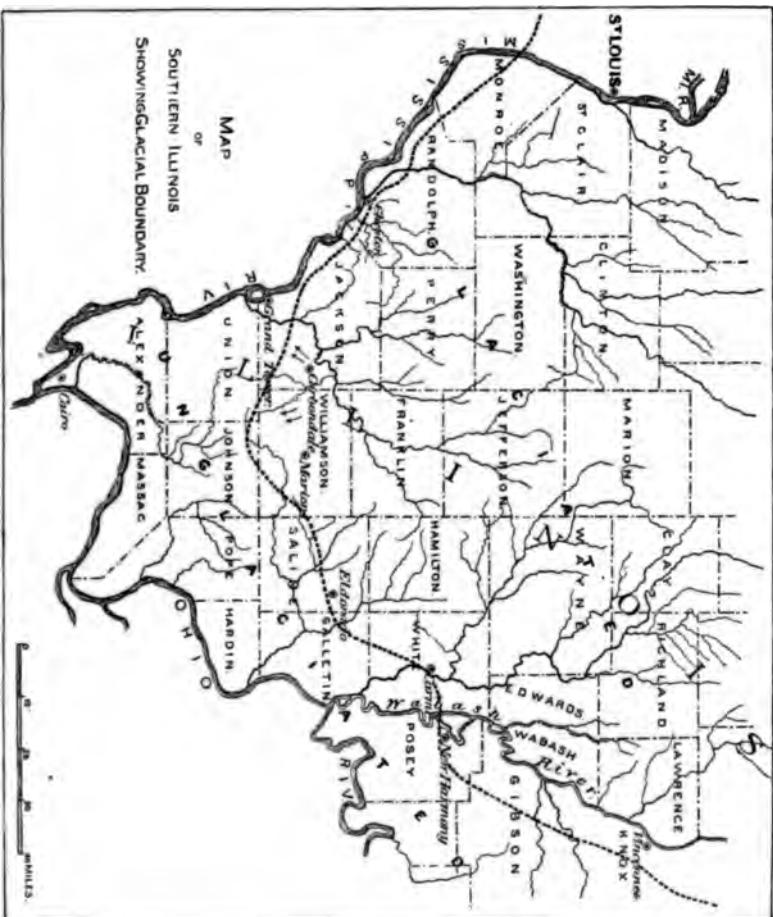
The glacial boundary in Illinois (see Plate V) first appears in White County near Phillipstown, and bears in a general southwesterly direction through Gallatin, Saline, and Williamson Counties, whence it bears northwest through Jackson, Randolph, and Monroe Counties, forming the east border of the Mississippi bottom-lands. But nowhere in this region are the glacial deposits thrown into ridges and hills as in the Eastern and Northwestern States, and they are everywhere buried, to a greater or less extent, by loess.

White County.—At Phillipstown the bluff facing the Wabash bottoms, opposite New Harmony, Ind., shows from twenty to thirty feet of till at the bottom, merging gradually into loess of about the same thickness. One-half mile west, compact blue till, containing fragments of rock and small boulders, appears at 10 feet below the surface.

Hawthorn and Emma townships are an extensive sandy plain not more than twenty or thirty feet above the Little Wabash.

Throughout Carmi and Heralds Prairie townships till with all its characteristics everywhere appears under the loess on the west bank of the Little Wabash. A characteristic section in the southwestern part of Heralds Prairie gives 11 feet of loess and 35 feet of till. No sharp line of demarcation between the two could be found. Granitic boulders 5 feet through occur in Carmi township. Mr. James Chilton reported a nugget of copper as found in section 28.

Gallatin County.—In Gallatin County glacial deposits are found only in Bear Creek, the northwestern township, where at Omaha station a considerable deposit occurs with granitic pebbles three or four inches through, which gradually merges into the loess above, and is reddish



1

color. A detour to Shawneetown, and thence to Equality, disclosed clearly marked glacial deposits.

Saline County.—Just north and west of Eldorado station, and 75 feet (barometer) above it, till, red in color, is exposed similar to that at Mahan, Gallatin County, but is absent to the southeast.

Till is abundant on the road from Eldorado to Raleigh. The soil is deep, and the granitic pebbles are much decomposed. At Raleigh the loess is more of a yellow cast.

An extensive detour in Harrisburg township disclosed no glacial marks. The loess was more red in color.

Numerous exposures of till at least ten feet deep appear in the northern sections of Brushy township. Granitic boulders two feet through are frequent. This is south of the Middle Fork of Saline River, the bottom-lands of which are about fifty feet below the general level.

Williamson County.—Till six to ten feet deep with the same amount of loess overlying, is exposed at Attila (120 feet above Marion). A similar deposit appears throughout the eastern part of Crab Orchard township. Striated stones are abundant. A trap-boulder, two and a half feet, was observed. The color of the loess was yellow; the depth of the till from five to ten feet.

At Sarahsville is an exposure of till covering several acres. Sections show 10 feet of loess, then 20 of till, in which are granitic boulders two and a half feet in diameter. The material is of various colors, red, orange, and yellow, and without stratification.

Deposits similar to that at Sarahsville continue to Creal Spring and Sulphur Spring, 200 feet above Marion, but they cease near the line of Johnson County, reappearing farther west on recrossing the Williamson County line.

Till is abundant in the southern portion of Grassy township, but disappears just before crossing the Union County line (at an elevation of 60 feet above Carbondale). In section 30, near the southwestern corner of the township, is a half acre of till like that at Sarahsville, where, on the sand rock exposed underneath, are distinct striæ already referred to (p. 42) as the most southern point in America at which striæ have been observed east of the Mississippi.

Jackson County.—Deposits of till are frequent in the northeastern and northern part of Makanda township, but do not extend to the higher lands in Union County. A striated surface was uncovered near the road, one and a half miles southwest of Carbondale; direction of striæ, S. 5° W. This is in section 29, Carbondale township. The covering till removed was from eight to fifteen feet.

Ridge township contains a fine exposure of till with abundant granitic pebbles, from six to eight inches in diameter, in section 1, T. 10 S., R. 1 W. From ten to fifteen feet of till is overlaid by the same amount of loess (165 feet above Carbondale). There is no till in the southern and central portions of the township, which is exceedingly rocky and

rough, though loess from ten to twenty feet is everywhere found; but till appears in the northwestern portion of the county in sections 5 and 8, T. 7 S., R. 4 W. (360 feet above Carbondale). Two miles west from this point the rocky bluff descends perpendicularly to the Mississippi, about four hundred feet below.

Randolph County.—The hill back of Chester (310 feet above the river) is covered very deeply with loess, in some places 100 feet. No till was observed within the city limits, but granitic pebbles were found in gulleys (210 feet above the river) north of the city. At Welga station, five miles back from the river, till abounds in great quantities with frequent granitic and striated boulders two feet in diameter. A fresh section here shows six to ten feet of loess, graduating rather suddenly into a gravelly stratum about ten feet in thickness resembling true till, resting upon soil filled with local fragments.

The contour of the country seems to have been largely determined by the direct glacial deposits, as the loess rested like a blanket of pretty even thickness over all, adjusting itself to previous irregularities.

MISSOURI.

A detour through Missouri from opposite Grand Tower to Perryville and to the river bank opposite Chester, Illinois, disclosed no sign whatever of glacial action, though everywhere there is a covering of loess, the general elevation being 300 feet above the river. The river valley all along is from five to seven miles wide.

Jefferson County.—Extensive detours in Jefferson County disclosed no true glacial phenomena there.

At De Soto (300 feet above the river) there was no loess on the hills, but everything was covered with a red residual clay full of local fragments.

St. Louis County.—West from Carondelet station there are no hills much more than 100 feet above the river, and all are covered with a blanket of loess about 20 feet deep. Sections show that this sometimes rests upon the unevenly eroded surface of the limestone, but sometimes also upon a thin stratum of well-rolled gravelly soil with an occasional granite pebble, but nothing like till was discovered.

Between Carondelet station and the business part of St. Louis, on the turnpike, numerous quarries and sink-holes, about one hundred and fifty feet above the river, show at the bottom of the loess a stratum of red clay a foot or more thick, containing granitic and other pebbles up to three inches in diameter. The depth of the loess is about twenty feet.

Near Forest Park, on the road to Ferguson, a section shows loess about 20 feet, with gravel from two to three feet at the bottom containing granitic and finely striated pebbles two or three inches in diameter. I found similar sections also near Hyde Park. This gravelly stratum was extensively uncovered in 1883 near the brick yards in the neighborhood of Shaw's Botanical Garden. Here many granitic and striated

pebbles were found. The upper terrace of the limestone was much eroded, and the gravelly stratum rested directly upon it. No striae was discovered upon the limestones in place, but thin fragments of limestone striated upon one surface were found. This is three miles back from the river (elevation about one hundred and fifty feet).

GENERAL REMARKS.

The Illinois Central Railroad from Chicago to Cobden, in the southern part of the State of Illinois, discloses but few glacial phenomena of interest to the transient traveler, though southward from Mattoon the color of the soil in the deeper cuts seems to be more distinctly red than to the north. The surface is covered with a fine, light colored silt, compact and without gravel and from one to two feet thick. Below is a reddish clay of undetermined depth, containing fine gravel of chert, quartz, limestone, and granite.

At Centralia sections fourteen feet deep showed white clay, three to five feet, with tough yellow clay containing quartz pebbles below. At Ashley a section of twelve feet showed two feet of white clay without grit, graduating into yellow clay containing an increasing amount of fine gravel with bowlderets and striated fragments lower down. At Du Quoin wells from seventeen to twenty feet in depth have two feet of loess with three to four feet of gravelly soil, with many striated and granitic pebbles lower down. Fragments brought up from the rock in place were striated. In Cobden, seven miles south of the glacial limit and 350 feet above Carbondale) there is no loess and there is no sign of glaciation; but there is much compact clay (see specimens 34 and 35).

At this point it will be profitable to give a more summary and explicit statement of the form of the glacial deposits over the glaciated margin traversed between the Alleghanies and the Mississippi River. As before remarked (page 55), a distinct, continuous terminal moraine along the southern margin of the glaciated region is not easily traced west of the Delaware River. Across the State of Pennsylvania the marginal accumulations worthy to be called a moraine (that is, consisting of knobs and ridges of any considerable height with inclosed kettle-holes), are found only at infrequent intervals, as already described (pp. 55-57). West of Pennsylvania such marginal accumulations are still more infrequent. The only places in the whole distance of the marginal belt surveyed between Pennsylvania and the Mississippi River in which I have encountered the features of a terminal moraine, such as exists south of New England and across the State of Wisconsin, are suggested, are the following:

In Columbiana County, Ohio, extensive ridge accumulations are found near Palestine on the eastern edge of the county, on one of the branches of Little Beaver Creek. These ridges were evidently formed by streams of water which issued into the valley from the ice-front, and in their composition resemble kames. In the western part of the county, at New Al-

exandria, upon the higher land in the county, and about 3 miles back from the border of the glaciated region, the deposits of till are as much as 50 feet deep, and are marked in a moderate degree by the knobs and kettle-holes characteristic of a true moraine.

In Stark County, next west, ridged accumulations of great size (80 feet high) with large kettle-holes occur within a mile of the extreme border of glaciation. These ridges are on a scale which compares favorably with the Kettle Range in Wisconsin, and the material, like that of the Kettle Range, is pretty largely water-worn. (See above p. 60.)

In Holmes County, though the glacial margin is sharply defined, and the glacial deposits are of considerable depth over the whole northern part of the county, there are no ridged accumulations of marked size except in the valley of the Killbuck, a few miles above Millersburgh. (See above, p. 60.)

In Knox County no extensive ridged accumulations were anywhere observed, though the depth of the glacial deposit is considerable down to within a short distance of the margin.

In Licking County in the vicinity of Wilkins Run, in Mary Ann township, there is an extensive marginal accumulation of terraces and kames, some of which are 92 feet high. A little farther to the south, also in Newark township, and very near the marginal line, the glacial deposit is marked by small hummocks and ridges at an elevation of 200 feet above the valley. In the southeastern part of Licking township, near the reservoir, there are extensive kame-like ridges from 15 to 30 feet above the level of the valley, which here drains through Jonathan Creek into the Muskingum. To what extent the base of these ridges is covered by deposits of loam and peat could not be ascertained.

Thorn township, Perry County, presents in its northern part a continuation of the phenomena in Licking township just described. The reservoir occupies a kettle-hole on the water-shed between a branch of Licking River and Jonathan Creek.

In Fairfield County the glacial limit is marked by ridges and hummocks of till at least 50 feet in depth, on the east side of Rush Creek. This is on land 200 feet above the valley. At Berne station there are hills of gravel from 50 to 60 feet in height brought down by the streams which drain the glaciated area in Pleasant township. In Hocking and Madison townships of this county the accumulations of till are very marked, being in some cases 40 feet in depth, at a height of 450 feet above the Hocking River, at Lancaster. Muddy Prairie, so-called, seems to be an immense shallow kettle-hole very near the margin.

In Ross County, at Adelphi, in the northeastern corner of the county, near the head of the valley of Salt Creek, the marginal accumulations are more marked than anywhere else in the State. Here, on the east, facing Salt Creek, they show a perpendicular section of 188 feet, and extend southwesterly through Colerain and Green townships, for sev-

eral miles to the Scioto Valley. The knobs, ridges, and kettle-holes are marked at various places within a mile of the southern limit of glacial signs. In Green township, on the eastern edge of the Scioto bottoms, kame-like ridges of gravel rise from 100 to 150 feet above the general level. West of the Scioto, at Lattas, in Concord township, ridges and knobs from 50 to 60 feet in height are numerous, resting on the flanks of the hill which faces to the northwest. The ice, however, surmounted this hill (which is about 400 feet above the general level to the north), and extended 3 or 4 miles, reaching the narrow valley of Paint Creek, in which, near the junction of Cat Tail Run, there are immense kame-like accumulations.

In Pike County the depression in the col between Bainbridge on Paint Creek and the headwaters of Baker's Fork of Brush Creek is filled to an indefinite depth by deposits of till, showing numerous ridges, knobs, and kettle-holes. This is on the extreme margin, and is about 200 feet above the bottom-lands of Paint Creek, and is flanked on the south by a level-topped loess deposit, extending for 2 or 3 miles. (For a fuller description of this, see pp. 92-96.)

Through the southeastern corner of Highland County and the north-western of Adams, the terminal accumulation is less marked than in Ross County; still the boundary of the glaciated region can be readily determined. In neither of these counties, nor in Brown or Clermont Counties, were there any ridged accumulations which could be properly called moraines, and I think that the same is true of Clinton County, and also of Hamilton, though the till is from 10 to 20 feet deep in the neighborhood of Walnut Hills station in Cincinnati, and 350 feet above the river, while at North Bend a preglacial channel extending from the Miami to the Ohio is filled by till to a height of 160 feet.

In Indiana the glacial deposits in the glaciated portion of Jefferson, Clarke, and Scott Counties are comparatively scanty. The deposit is much deeper over Dearborn, Ripley, Decatur, Jennings, and Bartholomew Counties, but though I traversed them in every direction, I nowhere encountered in them any ridged accumulations which properly could be called moraines. In Johnson County, however, where the boundary approaches the higher lands of Brown County, ridges and knobs of till were encountered in two or three places, and to some extent in the western part of Morgan County, but nothing of the sort appeared in Owen, Clay, Greene, Sullivan, Knox, White, Gibson, and Posey Counties.

In Illinois nothing like a moraine was encountered in any portion of the State which I traversed, which included Randolph, Perry, Franklin, Jackson, Williamson, Saline, Gallatin, and White Counties.

HYPOTHESIS OF A GLACIAL DAM AT CINCINNATI.

INTRODUCTION.

From the facts already stated it seems evident that the ice of the glacial period came down to the north bank of the Ohio River all the way from Brown County, Ohio, to Madison, Indiana, a distance, as the river runs, of more than one hundred miles, while it is equally clear that at points south of Cincinnati glacial ice extended across the river into Kentucky from six to ten miles. The acceptance of this conclusion raises some most interesting questions in speculative geology. The interpretation of the facts will depend upon whether the glacial deposits upon the north and south sides of the Ohio River belong to the same period or to different periods widely separated in time. The question also involves that as to whether the deposits upon the south side of the river were made before or after the Ohio had worn its present valley.

Upon the supposition that the long, narrow trough of the Ohio River (described on p. 57) was preglacial, the glacial deposits upon the south side at Cincinnati imply an ice dam between five and six hundred feet in height. Such an obstruction in the present condition of the valley would set the water back so as to submerge Pittsburgh to a depth of about three hundred feet, and affect the Alleghany River as far up as Oil City, and the Monongahela nearly up to Grafton, West Virginia.

Soon after the first announcement of these facts¹ Prof. I. C. White published a paper upon the terraces of the Monongahela River, which seemed to him in a remarkable degree to confirm the theory of an ice dam at Cincinnati.² To judge of the value of these individual facts it is necessary to take a more comprehensive view of the whole matter than has heretofore been possible, and to speak somewhat in detail of the terraces throughout the whole valley of the Ohio and its tributaries.

THE LOWER TERRACES OF THE OHIO AND ITS TRIBUTARIES.

The valley of the Ohio River above Louisville is characterized by two sets of terraces, the lower of which is very persistent throughout the whole course and is especially developed wherever tributaries from the glacial region enter it. So uniform is the increase in the height of a terrace in the Ohio Valley immediately below the mouth of its tributaries, coming from the glaciated area, that there can be no hesitation in attributing their deposition to the vast flow of water down these tributaries into the Ohio during the period in which the ice extended into their headwaters. The deposits in the Ohio below the mouth of Big

¹ *Am. Jour. Sci.*, 1883, 3d Series, vol. 26, p. 326.

² See *Proc. Am. Assoc. Adv. Sci.* 32d (Minneapolis) meeting, 1883, p. 212, and *The Glacial Boundary in Ohio, Indiana, and Kentucky*, G. F. Wright (*Western Reserve Historical Society*), 1884, pp. 81-86.

ver Creek in Pennsylvania, are typical of what elsewhere occurs, may therefore be described with considerable minuteness.



FIG. 4.—Map of the tributaries of the upper Ohio.

The towns of Beaver and Rochester, Pennsylvania, are built upon a terrace which is 120 feet above the level of the Ohio and but eight or ten feet south of the glaciated region. The composition of that part of the terrace occupying the terrace upon which Beaver is built, and downstream from the junction of Beaver Creek and the Ohio, differs remarkably from that upon which Rochester is built, on the angle up stream from the junction. In the angle below the junction of the streams the terrace is composed of rounded pebbles of quartzite, gneiss, and granite, some of them, even near the surface, being two feet in diameter. In the angle above the junction granite pebbles are exceedingly rare, and pebbles of sand more than two or three inches in diameter are scarce. The distinction is evident. To use Prof. Dana's terms when speaking of the Connecticut River and the White River,¹ the Ohio is the great distrib-

¹ See *Am. Jour. Sci.*, 3d Series, vol. 22, 1881, p. 466.

uter and the Beaver is here the principal *contributor*, of drift material. The Ohio does not itself have direct access to the boulders which had been transported by glacial ice, it being wholly outside of the glaciated region. The drainage basin of the Beaver is, however, strewn with glacial *débris* down to within a few miles of the Ohio; and, as the granitic boulders of that area were borne along by the swollen torrents at the close of the glacial period, on reaching the onward but less rapid current of the larger Ohio they would naturally be deposited at the junction of the streams and in the lower angle.

The one hundred and twenty to one hundred and thirty foot terrace, upon which the city of Beaver is built, continues upon the north side of the Ohio River downward to Vanport, two miles, where it crosses to the south side and continues below to Raccoon Creek. Here it reappears upon the north side and continues to Six Mile Run, reappearing upon the south side a little above Industry. From Industry down three or four miles it is again upon the north side, reappearing on the south side one mile from Georgetown, two miles from the Virginia line, where, according to my leveling, it is 112 feet above the river, and contains numerous granitic boulders two feet or more in diameter. It is evident that the whole valley from Beaver to Georgetown, 14 miles, was once filled with coarse gravel and pebbles to a height of about one hundred and twenty feet, the material being much coarser at Beaver than at Georgetown. A well-marked terrace, also containing granitic pebbles, is found on Little Beaver Creek, one mile from its mouth, and 130 feet above the Ohio.

Below the mouth of Little Beaver Creek, as far as Marietta, at the mouth of the Muskingum River, there is no tributary entering the Ohio which could have been charged with glacial floods or with glacial material. There is, therefore, as might be expected, a gradual but marked diminution below this point in the extent of the terrace deposits. At Steubenville the extensive terrace upon the east side, according to my measurement, is but 95 feet above low water, and at Martin's Ferry, opposite Wheeling, the extreme height of the terrace is 102 feet. In both these places the granitic pebbles are numerous, but are smaller than higher up the river. From Martin's Ferry to Marietta I have not examined the banks of the river. This increase in the height of the terrace was remarked by Sir Charles Lyell,¹ who estimates it as 60 feet high at the mouth of the Great Kanawha, and about eighty feet high at Georgetown.

The Muskingum River, which enters the Ohio at Marietta, is lined with terraces all the way up to its headwaters in the glaciated region. It was therefore an important contributor to the glacial drift of the Ohio. Consequently at Rockland, about twelve miles below Marietta, and where the Ohio turns at right angles to the west, we find a marked increase in the glacial terrace. Blennerhasset Island is but fifty or sixty

¹ Travels in America, second series, vol. 2, p. 224.

feet above low-water mark, and is occasionally completely submerged by floods. The terrace at Rockland, however, is nearly 50 feet above the present high-water mark. About five miles below, opposite Little Rockhocking, a terrace appears again upon the south side of the Ohio, corresponding in general elevation and character to that at Rockland on the north side. The terrace at Ironton is 90 feet, while at Portsmouth, below the mouth of the Scioto, another chief contributor of glacial drift, the terraces on both sides are 110 feet.

There are no other specially marked terraces at any considerable distance above the present high-water mark until reaching Cincinnati, just below the mouth of the Little Miami River, which was one of the most abundant contributors of drift material from the glaciated region. Here we find the upper terrace, upon which the main part of the old city of Cincinnati is built, to be about fifty feet above the present high-water mark, or 120 feet above low water. Twenty miles below, at Lawrenceburgh, Indiana, near where the Ohio is joined by the Great Miami (another most important contributor from the glaciated region), the terraces rise to 112 feet above low-water mark, or about eighty feet above the flood plain. The terraces here are of equal height upon both sides of the Ohio; but upon the west side are much broader, extending into the valley from one-fourth to three-fourths of a mile from the foot of the bluff. The valley itself between the bluffs is here about three miles wide. Farther down the river the upper terraces are of diminished height. At Warsaw, Kentucky, about 20 miles below, the highest terrace is ninety feet above low water, or about thirty feet above high water. At Madison, Indiana, 20 miles still farther down, the upper terrace is 85 feet above low water. From these facts it is evident that there is no need of supposing the Ohio Valley to have been filled up through its entire course with gravel to the height of the terraces where the streams enter from the glaciated region. But just below the mouth of each of those streams there was an excessive deposit, which formed a bar or slight dam, as is the case now in the Mississippi at the mouth of its present tributaries. The Ohio, then, at the close of the glacial period, would have presented a series of long pools, one stretching down to the vicinity of the mouth of the Beaver, where the water must perceptibly have shoaled for several miles. A second pool ended at Marietta, at the mouth of the Muskingum; a third pool extended to the mouth of the Scioto at Portsmouth; a fourth to the vicinity of Cincinnati. Below the mouth of the Great Miami there was no contributor of glaciated material to obstruct the channel with its excessive deposits until reaching the mouth of the Wabash. There can be no question that this series of high terraces belongs to the closing stages of the last glacial epoch, if there were two epochs. The present flood plains are deposited in a channel which has been worn out of these larger deposits of the glacial period. And, as already noted, these glacial terraces are but parts of a still deeper de-

posit filling an old preglacial channel which was one hundred and fifty or two hundred feet deeper than the present trough.

All the southerly flowing streams which rise in the glaciated region are marked at the points at which they enter the unglaciated district by terraces of exceptional height (but never exceeding 160 feet), containing many granitic pebbles, and gradually diminishing, both in height and in the size of the pebbles, as they recede from the glacial boundary. Such terraces are specially noticeable at the following localities:

In Pennsylvania, on the Delaware River, at Belvidere; on the Lehigh River, at Bethlehem; on the Susquehanna, at Berwick; on Fishing Creek, below Benton; on the Loyalsock, above Montoursville; on Locoming Creek, below Ralston; on the Conewango, below Ackley Station; on Big Broken Straw Creek, at Spring Creek; on Oil Creek, at Titusville; on French Creek, above Franklin; on Big Beaver Creek, at Chewtown.

In Ohio, on the middle fork of Little Beaver, at New Lisbon; on the east branch of Sandy Creek, a tributary of the Tuscarawas, at East Rochester; on the Nimishillen, just below Canton; on the Tuscarawas, near Bolivar; on Sugar Creek, another tributary of the Tuscarawas, at Beech City and Deardoff's Mills; on the Killbuck, another branch of the Tuscarawas, below Millersburgh; on the Mohican, above Gann's Station; on the Licking, at Newark; on Jonathan Creek, near Thornville (the last eight all empty eventually into the Muskingum); on the Hocking River, at Lancaster; on the Scioto, a few miles above Chillicothe.

In Indiana, on the east fork of the White River, at Seymour, and on the Wabash, near New Harmony.¹

THE UPPER TERRACES OF THE OHIO AND ITS TRIBUTARIES.

Disconnected with the lower set of terraces, there is another, which is far more difficult of interpretation, and which stands at a much higher level. We will note the places where this upper set of terraces is most conspicuous, beginning below Cincinnati and going towards the source of the river.

I am inclined to reckon, as belonging to this series of upper-terrace formations, the conglomerate (described on page 64) near Woolper Creek, a few miles above Bellevue, in Boone County, Kentucky, and 25 miles below Cincinnati. What is here known as Split Rock is but a dismembered portion of a level-topped terrace of cemented gravel rising 185 feet above low-water mark, and extending back from the river from one-half to three-quarters of a mile, and a mile or two along the sides of the valley. A deposit precisely similar occurs a mile and a half back from the river, near the headwaters of Middle Creek, about three hundred and fifty feet above low water mark.

¹ For fuller information on this subject, see *Am. Jour. Sci.*, July, 1882, pp. 8-14; *Geol. Survey, Ohio*, vol. 5, pp. 761-762.

I am inclined also to classify with the upper terraces some cemented gravel containing granitic pebbles, and similar to this at Split Rock, and on Bracken Creek at its junction with the Ohio just above Augusta, Kentucky, about fifty miles up the river from Cincinnati. The summit of this is about two hundred feet above low-water mark. The pebbles of the conglomerate are very coarse, and numbers of them are granitic and from three to four inches in diameter. A similar conglomerate occurs upon the opposite bank, near Higginsport, Ohio.

Going up the river, an instructive remnant of the higher terrace is found on the east side of the Ohio River a little below Steubenville, Ohio, opposite the lower ferry, and about twenty miles above Wheeling, West Virginia. At this point the representative of the lower terrace previously described is about one hundred feet above low-water mark, and is well developed. But farther back from the river, on the West Virginia side, numerous granitic pebbles occur at an elevation of 50 feet higher, and included in an extensive deposit of sand, whose upper limit is 285 feet above low-water mark, or about one hundred and eighty-five feet above the lower terrace. Just to the north of this point the rocks in places project to the river's bank, at an elevation of four or five hundred feet above the river; thus during excessively high water favoring the formation of the deposit just described.

The remnants of the upper terrace below Steubenville correspond in general character and in elevation above the river to those seen between the mouth of Beaver Creek and Pittsburgh, of which the best is at New Brighton, on the east side of the Beaver not far from its junction with the Ohio. Here there are remnants of a terrace preserved upon a rocky shelf and containing many rounded pebbles of granite 215 feet above the Beaver, and 260 feet above the Ohio. This is several miles outside the extreme limit of direct glacial action. The pebbles are at the bottom of a thin deposit of cream-colored clay which is used for brick-making.

A similar terrace exists back of Middletown, Alleghany County, on the south side of the Ohio River, 12 miles below Pittsburgh. Here, at a height of from two hundred and fifty to two hundred and eighty feet above the river, rolled fragments are abundant; and among them occasional pebble of granite.

A third noteworthy remnant of a terrace between the mouth of the Beaver and Pittsburgh occurs at Bellevue, in Ohio township, Alleghany County, Pennsylvania, on the north side of the Ohio, about five miles below the mouth of the Alleghany River.¹ Here, upon a shelf of rock rising the river, in a perpendicular cliff, between two hundred and twenty and three hundred feet in height, there is the remnant of a terrace whose surface is 310 feet above low-water mark and containing many granitic pebbles. This terrace is about half a mile in width. A well

¹ See I. C. White, 2d Geol. Survey, Pa., Q. p. 175.

sunk from the surface was reported to me as passing through 20 feet of tough clay and 25 feet of sand, coarse gravel, and quicksand, showing pebbles at the bottom a foot or more in diameter. At that level springs come out facing the river. Facts concerning analogous terraces on the Monongahela are detailed in the next section.

THEORETICAL EXPLANATIONS.

Here we may well pause to consider the theoretical elements of the problem, and ask, by what combination of forces known to be in operation could this terrace of gravel at Bellevue, which incloses pebbles of northern drift, be deposited nearly three hundred feet above the present level of the Ohio River, and 1,000 feet above tide? The granitic pebbles must by some means have been brought down the Alleghany River from as far up as Franklin, a distance of 125 miles. To account for this terrace and some others which I shall presently mention, there are only three possible hypotheses, each involving in some form the aid of the glacial theory. These hypotheses are (1) that during or since the glacial period the whole region of the upper Ohio passed through a period of subsidence, the limit of which is marked by these upper terraces; (2) that there has been some local obstruction like that of the supposed Cincinnati ice dam; (3) that the upper terraces were formed during an earlier glacial epoch when the rocky beds of the streams occupied a higher level than now.

That these upper terraces are coincident in date with, or subsequent to, a glacial epoch is clear from the fact that the granitic elements entering into their formation could have been brought into the headwaters of the Alleghany River only by a movement of glacial ice from the distant north. After being left by glacial ice in this region, they were within reach of streams of water which could transport them an indefinite distance towards the Gulf of Mexico. Such granitic pebbles from the glaciated region are, at the present time, transported by flowing water far down the Ohio River, and even into the Mississippi. But, whether rolled along upon the bottom or transported upon floating ice, they can now be deposited along the stream only to the height of the present flood-plain, which is nowhere more than seventy feet above the bottom. The present problem is how to account for them in terraces 300 feet above the river.

THE UPPER TERRACES THE REMNANTS OF A DISTINCT GLACIAL EPOCH EARLIER THAN THAT PRODUCING THE LOWER.

There is no question but that these facts may be accounted for on the theory that there have been two glacial epochs, in each of which the ice extended into the headwaters of the Alleghany; and that these high terraces were formed during the first glacial period, as the present flood-plain of the river is formed, but when the bed of the river was *between two and three hundred feet higher than it is now*. This, how-

ever, would involve the supposition that sufficient time elapsed between the first glacial period and the second for the Ohio and its tributaries to wear down their channels through their rocky bed, and along their whole length to a depth of between three and four hundred feet. If we accept without question the theory of two glacial periods so nearly equal in extent and separated by such a vast interval of time, this is the easiest way to account for the facts as so far presented.

But without questioning the fact of two distinct glacial epochs, we may question the propriety of accounting for this terrace by a glacial epoch so far back in time as this theory supposes. From the Falls of the Ohio at Louisville, Kentucky, to the head of the Alleghany, for a distance of about one thousand two hundred miles the stream has lowered its bed through the rocks to a depth of more than four hundred feet below the bottom of the terraces in question. For the testimony is unequivocal that the rocky bottom of the Ohio River from the Beaver down is not more than two hundred feet below its present bottom. The time necessary for this amount of erosion is enormous.

FACTS ADVERSE TO THIS THEORY.

Now, there are many facts which would seem to forbid such an enormous lapse of time between the deposition of these upper terraces containing granitic pebbles and the formation of the lower terraces containing similar material, as before described. In the first place, vegetable and animal remains of recent species are found in a very fresh state of preservation in river deposits of the Ohio Valley corresponding in age with the upper terraces in question.

Terraces on the Monongahela.—The first instance has been carefully described by Prof. I. C. White, and occurs on the Monongahela River, near Morgantown, West Virginia. The trough of the Monongahela, which joins the Alleghany at Pittsburgh to form the Ohio, is in every way similar to that of the Alleghany, with the single exception that the terraces which line its banks at heights corresponding to those of the Alleghany and the upper Ohio, contain no pebbles of northern drift but consist wholly of material which is native to the valley itself. At numerous places, as Professors White¹ and Stephenson have pointed out along the Monongahela, and as I myself have since observed, there are extensive deposits of pebbles and boulders from two to three hundred feet above the river, especially near where the tributaries enter. Many of these deposits may well enough be regarded as the river pebbles left in the channel when it flowed on a rocky bottom two or three hundred feet higher than at present. Such places may be noted at Belle Vernon, Brownsville, and Masontown, in Fayette County, Pennsylvania, and Greensborough, in Greene County, Pennsylvania. But, in the opin-

¹ See *The Glacial Boundary in Ohio, Indiana, and Kentucky*, G. F. Wright (Western Reserve Historical Society) pp. 82-84.

ion of Prof. White, the deposits near Morgantown, West Virginia, can not be so easily explained in this manner. I transcribe Prof. White's description, premising that his familiarity with the region is greater than that of any other competent observer.

In the vicinity of Morgantown, terraces of transported material occur at the following approximate (measured by barometer) elevations:

Terraces.	Feet above river.	Feet above tide.
First	30	80
Second	75	85
Third	175	95
Fourth	200	99
Fifth	275	1,065

The first terrace is the present flood-plain of the river, consisting principally of fine sand, mud, and gravel. * * *

All of the other terraces have thick deposits of transported material, wherever the original contour of the surface has favored its preservation from erosion. From the top of the fourth terrace Mr. Keck dug a well through seventy feet of clay, gravel, and boulders without finding bed rock. He also encountered logs of wood in a soft or semi-rotten condition near the bottom.

Many other wells on the third terrace have been sunk to depths of 20 and 30 feet without reaching bed rock. * * *

Owing to the considerable elevation—275 feet—of the fifth terrace above the present river bed, its deposits are frequently found far inland from the Monongahela, on tributary streams. A very extensive deposit of this kind occurs on a tributary one and a half mile northeast of Morgantown, and the region, which includes three or four square miles, is significantly known as the "flats." The elevation of the "flats" is 275 feet above the river, or 1,065 feet above tide. The deposits on this area consist almost entirely of clays and fine sandy material, there being very few boulders intermingled. The depth of the deposit is unknown, since a well sunk on the land of Mr. Baker passed through alternate beds of clay, fine sand, and muddy trash to a depth of 65 feet without reaching bed rock. In some portions of the clays which make up this deposit, the leaves of our common forest trees are found most beautifully preserved. Whether or not they show any variations from the species growing in that region the writer has not yet had time to determine, but when a larger collection has been obtained, this subject will receive the attention that it deserves, since if the date of the glacial epoch be very remote, the species must necessarily show some divergence from the present flora.

Of animal remains the only fragment yet discovered in this highest of terraces is the tooth of a mastodon, dug up near Stewartstown, seven miles northeast from Morgantown.

More recently Prof. White¹ contributes other interesting facts which concern the terraces farther up the Monongahela, and which can best be quoted in this connection:

Owing to the nature of the topography, and the country rock along the draining streams, the region along the upper Monongahela has these terrace deposits in better preservation than any other with which the writer is acquainted, and this is especially true of the West Fork branch of that stream. It is along this line that the *existence of a great submergence* which covered the country with a thick coating of

¹ Am. Jour. Sci., 3d series, vol. 34, 18-7, pp. 378, 379.

transported material up to a certain level, is most conclusively shown. In the region of Morgantown, on the main Monongahela, these terrace deposits end at about two hundred and seventy-five feet above low water, or 1,065 feet above tide, while at Fairmount, 28 miles above, there is a vast amount of this terrace material thrown down about the junction of the Valley and West Fork Rivers, and the upper limit of the same is a little over two hundred feet above low water, which is here 850 feet above tide.

About twenty miles farther up the river (West Fork), near Shinnston, the upper limit of the terrace material is found at 160 feet above the water, but here the latter has an elevation of about eight hundred and eighty-five feet above tide.

At Clarksburgh, where the river unites with Elk Creek, there is a wide stretch of terrace deposits, and the upper limit is there about one thousand and fifty feet above tide, or only 130 feet above low water (920), while at Weston, 40 miles above (by the river), these deposits cease at 70 feet above low water, which is there 985 feet above tide. It will thus be observed that the upper limit of the deposits retains a practical horizontality from Morgantown to Weston, a distance of 100 miles, since the upper limit has the same elevation above tide (1,045-1,065) at every locality.

These deposits consist of rounded boulders of sandstone, with a large amount of clay, quicksand, and other detrital matter. The country rock in this region consists of the soft shales and limestones of the Upper Coal Measures, and hence there are many "low gaps" from the head of one little stream to that of another, especially along the immediate region of the river, and in every case the summits of these divides, where they do not exceed an elevation of 1,050 feet above tide, are covered with transported or terrace material, but where the summits go more than a few feet above that level, we find no transported material upon them, but simply the decomposed country rock.

A fine example of one of these bowlder-covered divides may be seen at the mouth of the Youghiogheny River, back of McKeesport, Pennsylvania. The "divide" in question is one between the waters of Long Run, which puts into the Youghiogheny 10 miles above McKeesport, and that of another little stream which heads up against it, and flows into the Monongahela within the city limits. The divide between these two water-ways, although 275 feet above the level of the river, is almost imperceptible, a broad and bowlder-covered valley through which there is not the slightest doubt that the waters of the Youghiogheny once flowed during the epoch of submergence.

Another typical illustration of these terraces in the valley of the Monongahela occurs at Carmichael's, Greene County, Pennsylvania. Carmichael's is about five miles west of the river and (as shown in the accompanying map) about the same distance from an angle in the stream which it makes in turning to the north. The village is built on what is called the "Glades," which extend about two miles in one direction and three in the other. The Glades are about two hundred and fifty feet above the river, and from one to two hundred feet below the general level of the country, and are connected by a pretty well defined channel at about the same level with the river both above and below. Above, this old river channel is continuous with one on the east side near Masontown—the two old channels forming a sort of a double oxbow in the reverse direction from those in the present bed of the stream, and about two hundred and fifty feet above it. The whole course of this old channel is marked by rounded pebbles, such as are found at the bottom of the present river, and these are covered more or less with several feet of loam. The glades at Carmichael's are simply an enlargement in this old channel. But at Carmichael's a log of wood

was reported to me as found buried 30 feet in the sand. Much quicksand is found from 15 to 20 feet below the surface. It hardly seems



FIG. 5.—Map of the old channel of the Monongahela, between Masontown and Carmichael's, Virginia.

possible that wood should have been preserved in such a situation during all the immensely long period required for the river to lower its bed through the rock to its present level. Many of the river pebbles may belong to the earlier period, but after eliminating the effects of that early cause it is difficult to resist the conviction that most of the fine loam and quicksand, together with the buried wood, belong to a much later period of deposition. It is easy to see that with the water standing at about that level throughout the whole valley, wood and clay and sand would come down from the higher reaches of the river and be deposited in such sequestered places. Any cause that can be shown to have acted in recent times to raise the water to that level will furnish the most natural explanation of the facts.

Wood has been found also in a similar situation in the remarkable terrace on the Alleghany River, near Parker, Pennsylvania. Here also there is a sort of a double ox-bow at a level of about two hundred and fifty feet above the present bed of the river. But, unlike the gravel at Carmichael's, the gravel here is partly composed of granitic pebbles, though far outside of the region of the direct action of glacial ice. Like that at Bellevue, on the Ohio, this gravel bears unmistakable evidence of having been deposited during the glacial period. The wood was reported as dug from quicksand in a well two miles east of the Alleghany, near the eastern limit of the high deposit containing the pebbles just mentioned. It should be noted, however, that the absolute level of this deposit at Parker is somewhat higher than that at Bellevue, but it scarcely differs at all from that of the fifth terrace described by White as extending from below Morgantown, West Virginia, to Clarksburgh.

River deposits in Teazes Valley, West Virginia.—Still another instance of wood which has been preserved in a deposit of the glacial age is worthy of minute description. In this case I have the advantage of having found it myself. The locality to which we are now transferred is that of Teazes Valley, Putnam County, West Virginia. This valley runs

the Kanawha River, a little below Charleston, to the Ohio at the mouth of the Guyandotte, near Huntington. The valley is clearly a remnant of early erosion, when the water of the Upper Kanawha took that course to join the Ohio. The valley is very clearly

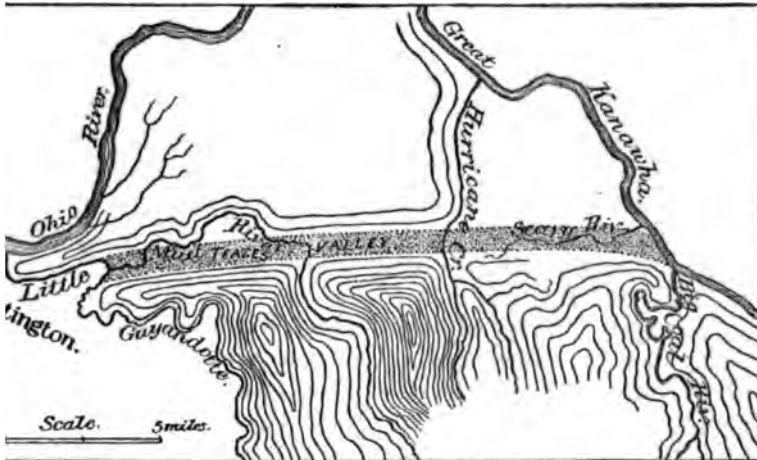


FIG. 6.—Map of Teazes Valley, West Virginia.

1, being about a mile wide and from two to three hundred feet higher than the hills on either side, and having a remarkably level floor throughout the greater part of its course. The bottom of the valley is throughout with a deposit of river pebbles covered many feet deep with a mixture of sand and clayey loam. (See Plate VI.) In some places this loam is from thirty to forty feet deep, extending for several miles without interruption, as at Long Level, about the middle of the

Here a section about one-half mile long and 25 feet deep shows at the top a stiff stratum of clay containing wood at a depth of seven feet. Immediately below is sand containing much iron and cemented together by the infiltrations of the ore. The stratum above containing wood had never been disturbed, and the wood, a small specimen of *Pinus strobus*, of some coniferous tree, is remarkably fresh in its whole appearance. It is scarcely possible that it should have remained in its position during all the time required for the erosion of the Ohio River and its tributaries from the level of Teazes Valley to its present level, 250 feet below. Besides, there are many other things to show that the deposit was in slack water rather than on the bed of a running stream. Unlike the deposits of a river on its bed, in this case the silt extends clear across the valley, covering the bottom to a uniform depth, except where it has been removed by recent irregular erosion. A single cut in this silt, shown in Plate I, is one-half mile or more in length.

Further evidence of the recent date of this deposit of river silt as compared with the erosion of the valley, appears in the relation of the

transverse valleys to it. Mud River and Hurricane Creek are two small streams rising some little distance to the south of the valley, but now either joining or crossing it at a level sixty or seventy feet lower than that of the rocky bottom of the valley (see map of Teazes Valley). Mud River joins the valley at Milton, and then turns west and follows its course to the Guyandotte. But its level even above where it now joins the valley is 120 feet lower, and this a channel worn in the solid rock. Hurricane Creek is a still smaller stream, and crosses the valley within a few miles of its eastern end, emptying into the Kanawha some miles farther down. Where it crosses the Teazes Valley its bed is sixty or more feet lower down in the rock than that on which the pebbles and silt rest throughout the valley, and these deposits come down on the rocky shelf bordering the Hurricane in a way to show that it could not have remained where it is during the time required for so small a stream to wear down so extensive a channel.

The old river valley in Boyd County, Kentucky, back of Ashland, is really a continuation of Teazes Valley, which then continued down as far as opposite Hanging Rock, just below Ironton, Ohio. It was the river pebbles in this part of the old valley, just back of Ashland, which deceived some of the earlier observers, and led to the impression that there were signs of the actual presence of glacial ice in this county in Kentucky. On close examination, however, it appears that the pebbles are all regular river pebbles, and moreover are all from the valley of the Kanawha. Especially there is to be noted a dark-colored flint peculiar to the mountains of West Virginia.

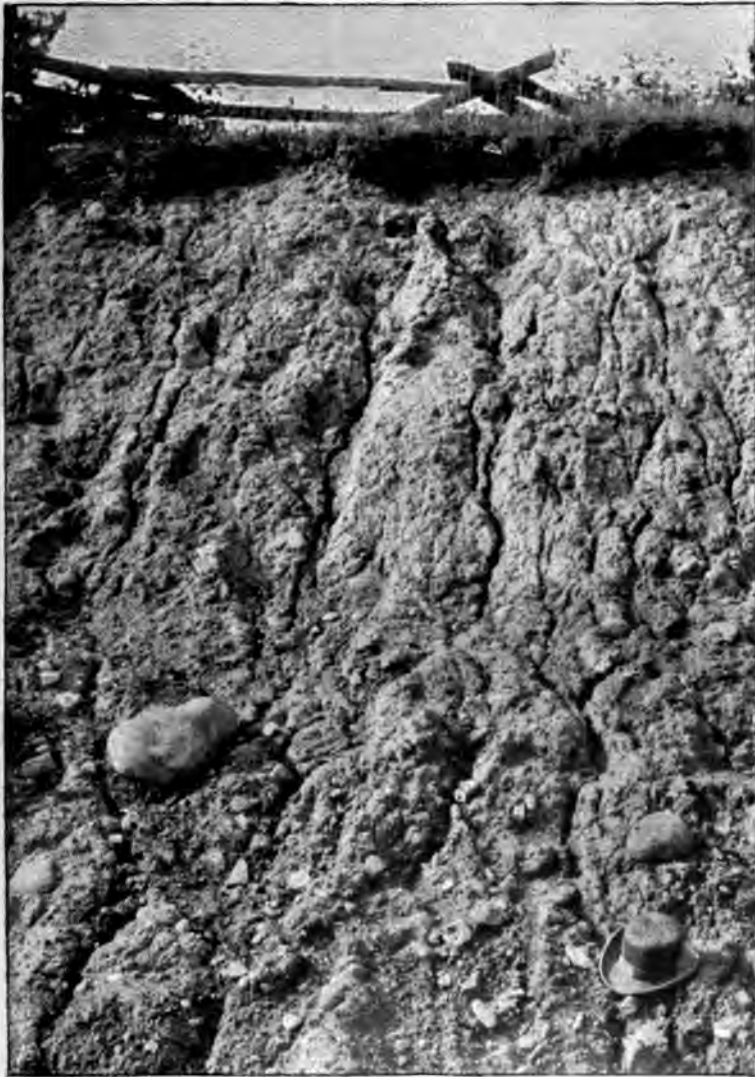
Terraces on the Big Sandy.—But wood is not the only perishable material whose preservation is significant. Pebbles of the soft sandstones of the coal measures are almost equally perishable, and Prof. L. C. White reports accumulations of these at various points at high levels on the southern tributaries of the Ohio. One such instance is on the right bank of the Big Sandy, 10 miles above its junction with the Ohio. Here Professor White¹ has described a deposit of rounded and flattish bowlderets from two to four inches in diameter and 450 feet above the stream (950 above tide). "These rounded bowlders of local coal measure sandstone [in the opinion of Prof. White] could hardly have resisted the elements during the long time since the Big Sandy Valley existed at this 400-foot level."

The hill on which they occur is a topographical summit for the immediate vicinity so that this does not represent the highest deposits of such a nature in the region. A similar deposit occurs on the Guyandotte, at the mouth of White Oak Creek, where a bed of bowlders was observed by Prof. White extending up to 150 feet above the river, or to 925 above tide.²

Terraces on the Elk River.—A still more significant collection of such

¹ Am. Jour. Sci., 3d series, vol. 34, 1887, p. 375.

² Loc. cit.



SECTION OF DEPOSIT NEAR HURRICANE, IN TEAZES VALLEY, WEST VIRGINIA.



at near the junction of the Elk with the Kanawha is thus de-
 in a communication to me by the same experienced observer :

the Kanawha meets the Elk at
 on, West Virginia, a great bed of
 trash extends to 225 feet above
 r (780 feet above tide), among
 re large numbers of metamorphic
 on the Blue Ridge region of Vir-
 Many boulders go much higher,
 me extend to 390 feet above the
 to 945 feet above tide.

the best pieces of evidence for
 al dam that I have found, out-
 eazes Valley, may be seen a short
 up the Elk River, at the summit
 vide separating the waters of two
 eams, which both empty into the

we find a deposit of clay, boulders,
 r trash on the summit of the di-
 d how it could have got there ex-
 n backwater of some kind cover-
 surface there I am at a loss to un-
 l.

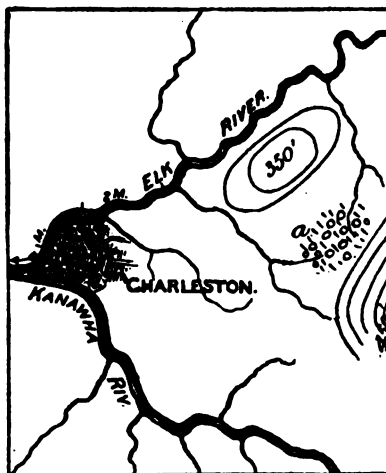


FIG. 7.—Outline map of Elk River, West Virginia.

her instance of possibly still greater significance has been re-
 by Professor White since the above was in type. It occurs on
 ter-shed between the west branch of the Monongahela and
 Island Creek, which empties into the Ohio some distance above
 ta. The Parkersburgh branch of the Baltimore & Ohio Railroad
 a cut in this summit about fifteen miles west of Clarksburgh,
 Virginia. There is here "a broad level summit, having an ele-
 of 1,100 feet, in a gap of probably 300 feet below the inclosing
 That gap, or valley, is covered by a deposit of fine clay. The
 rough it is about thirty feet, and one can observe the succes-
 clays of all kinds and of different colors, from yellow on the
 down to the finest white potters' clay at the level of the rail-
 here the cut reaches bed-rock, thus proving that the region has
 abmerged." This submergence would carry a water-level up the
 any Valley so as satisfactorily to explain the phenomena there
 ted by some to a first glacial epoch. Speaking of the theory of
 ent Chamberlin, that all these deposits in the Monongahela Val-
 re connected with the formation of the benches which slope
 ard, and were the result of erosion, Professor White claims
 subsequent to the erosion of these benches all of them were cov-
 ith lacustrine deposits. The proof of this is found in the fact
 ong the Monongahela and its tributaries there is at the summit
 lacustrine level a deposit of clays and boulders and erosion
 of every description, beginning at 1,100 feet above sea-level and
 ing down to the present flood-plain. Now, on the Baltimore and

Ohio Railroad (at the point before described) there is, it seems to me, an absolute proof of this submergence, because the old valley slopes there on the one hand into the Ohio and on the other into the Monongahela, and yet the summit has 30 feet of a clay deposit, and on this summit, and on other tributaries of the Monongahela, these clay deposits cease at altitudes of 1,075 to 1,100 feet, and above that level there is no deposit—there is simply the decomposed shale and rocks in place. Why should these clay deposits cease near that prescribed level if there has been no submergence during the later history of this valley?¹

Terraces in Bath County, Kentucky.—Mr. G. H. Squier has also furnished me facts of a similar character concerning deposits in the upper portion of the valley of Licking River, Kentucky. In Bath County he found over an extensive region of low table-land, between Slate Creek and Licking River, and for some distance to the north, large numbers of water-worn pebbles, composed of white quartz, chert, black shale, and sandstone, and, most remarkable of all, fragments of water-worn coal. These are spread, not over the low table-land and in the valleys, but over the lower hills; but do not extend vertically as high as the watershed. The pebbles of sandstone and coal must have been brought down the streams at least twenty miles, and it is evident that they could not have been left upon this table-land and these low hills by running water. They are just such deposits as would occur during the existence of a temporary lake into which floating ice from the east could bring and deposit the materials in the situations indicated.

It may seem an insuperable objection to the foregoing theory of an ice dam, that at Oil City there is a terrace in the fork of the Alleghany with Oil Creek, which is 325 feet above the river, and that granitic pebbles appear in this. The low-water mark in the river at Oil City is about nine hundred and sixty feet above tide, which would make the elevation of this terrace 1,285 feet above tide. Also at Tidionte, about thirty miles farther up the river, glacial terraces are found on both sides of the river at just about the same absolute level. The solution of this difficulty may be found, on this theory, by supposing another ice dam in the Alleghany, at Franklin, Pennsylvania, and direct evidence of such an obstruction is not wanting. On reexamining the region with a view to correcting the glacial boundary as originally laid down by Prof. Lewis and myself, I found abundant evidence that former suspicions as to the incorrectness of our inferences were amply justified, and there can be no doubt that glacial ice at one time covered the hills down to the Alleghany River both above and below Franklin. Both above and below the angle of the Alleghany at that point I found granitic boulders and scratched stones at elevations of from four to five hundred feet from the river, and farther east than the western angle of the river.

¹ Bulletin of the Geological Society of America, vol. I, pp. 477-479.

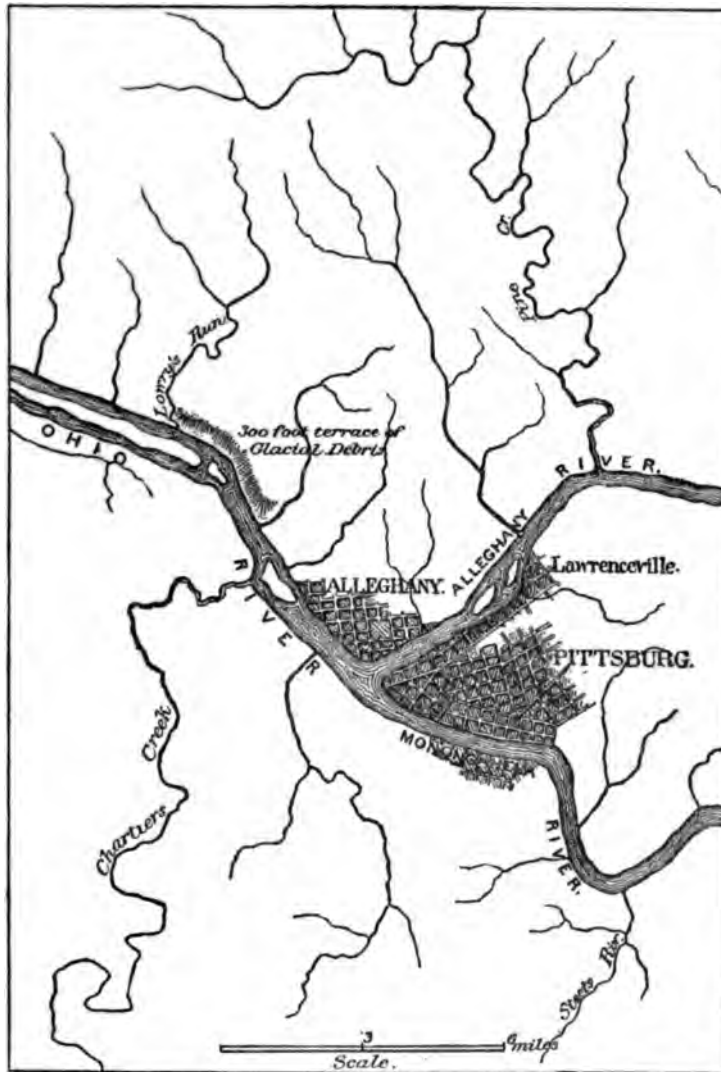


FIG. 8.—Map showing terrace at Bellevue, Pa., and the relation of Chartiers Creek to the Allegheny River.

Beech Flats, Pike County, Ohio.—Another crucial case is to be found in Pike County, Ohio, at the headquarters of Brush Creek. By reference to the accompanying map it will be seen that at the height of the glacial period the front of the ice rested at the northwest corner of Pike County, and that the divide between Paint Creek and Baker's Fork of Brush Creek is formed by the extreme portion of the direct glacial deposits. Before the glacial period there was a continuous depression connecting Paint Creek with the valley of Brush Creek, though not suffi-

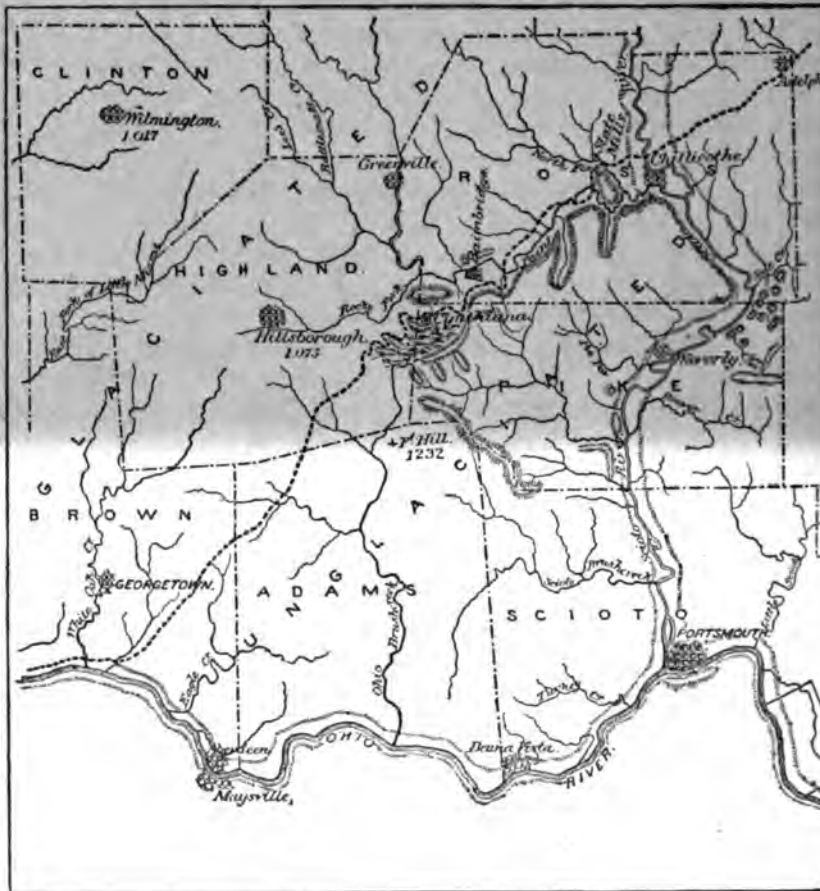


FIG. 9.—Map showing the still-water deposit between Paint Creek and Brush Creek, southern Oh

ciently low to make it the line of drainage. At a point about five miles south of Bainbridge, on Paint Creek, this depression is filled up, from side to side, to a height of about two hundred feet, with a true glacial deposit containing numerous northern boulders and scratched stone. On the northern side, towards Paint Creek, this deposit exhibits every mark of a terminal moraine, with its characteristic knobs, ridges, and kettle-holes; while to the south of it there is an extensive plain, known

in the locality as the "Beech Flats." This, too, consists largely of transported material from the north; but it is level topped, and is considerably higher than the valley of Baker's Fork, which heads in it and runs to the south, emptying, finally, into the Ohio River. Its elevation is about nine hundred and fifty feet above tide.

The significance of this condition of things cannot be fully apparent without a discussion of the remarkable facts connected with the valley of Paint Creek between Bainbridge and its junction with the Scioto River. From examination of the map it will appear that the course of this creek below Bainbridge is in a northeasterly direction, parallel with and along the very margin of the glacial boundary. The valley of the creek is here about a mile wide, and is bounded on either side by steep banks leading up to the table-lands about five hundred feet above the stream. We cannot, as yet, be certain whether during the glacial period the ice extended to the southeast side of this valley for several miles below Bainbridge or not. But, as Prof. Orton¹ long ago pointed out, the preglacial outlet of Paint Creek was certainly for a time completely obstructed by ice. This preglacial outlet continued onward in a northeast direction till it was joined by the North Fork, at Slate Mills (shown on the map), where it turned to the right and pursued its course through a broad valley to join the Scioto below the present site of Chilliworth. It appears at a glance that, while the ice during the glacial period occupied the northeastern end of the valley, in the vicinity of Slate Mills, the drainage was compelled to seek a more southern outlet. A visit to the locality also makes it evident that after the ice had withdrawn, glacial deposits in that part of the valley presented a barrier to the occupation of its former channel by Paint Creek, compelling it to seek an outlet by a cut-off across a point of the table-land extending up to Slate Mills from the south. The evidence that Paint Creek has occupied this cut-off only since the glacial period appears primarily in the fact that the narrowness in that part of the gorge is in striking contrast to the other portions of the valley. It has not had time to enlarge as other portions of the valley have. Whereas other portions are about one mile wide at the bottom, this is not over 500 feet.

As before remarked, the table lands are here about five hundred feet above the valley of Paint Creek, and are built up of parallel strata of soft shale underneath and Waverly sandstone on the surface, the shale occupying here much the larger portion of the perpendicular height. It was Prof. Orton's opinion that this cut-off was formed by the action of the water which flowed along the front of the ice while it closed the lower part of Paint Creek Valley, in the vicinity of Slate Mills, and it has even been suggested that this might serve as a measure of the length of time during which the ice-front remained at this point, the problem being how long time would be required for the formation of

¹Second Geol. Survey, Ohio, vol. 2, pp. 653-655.

such a gorge in such strata, the distance being in the neighborhood of two miles, and the strata being favorable to rapid erosion.

But, upon further examination and more mature reflection, it seems to me doubtful whether that can with certainty be called in its whole extent a postglacial gorge. The little stream seen upon the map to enter the cut-off at its southern angle is in itself an eroding agency of considerable importance, having worn back since the glacial period a tributary gorge no less than 600 feet in length; so that it is by no means impossible that the whole gorge across the promontory may have been formed by this and perhaps another stream flowing one to the east and the other to the west. If this cut-off had been thus formed in large part before the glacial period, then but a very short time would have been required to scour out the shale in the lower part of its bed, so that the extensive glacial deposits in the vicinity of Slate Mills should permanently turn the stream through the cut-off, where it now flows. As the result of my last visit to the locality, I am inclined to place the glacial boundary a little south of the cut-off, and make it follow the southeastern side of Paint Creek Valley up to Bainbridge. At any rate I have found granitic pebbles on the table-land for some little distance south of the cut-off.

My notes report that not only granitic but occasionally scratched pebbles were found upon the farm of Mr. A. T. Long, in Huntington township (400 feet above the level of Paint Creek), and that one sandstone fragment two feet in diameter was distinctly striated. More extensive deposits of gravel containing granitic pebbles were found at a level 150 feet lower than Mr. Long's farm, on either side of the water-shed between the creek above the cut-off and the creek below the cut-off, and from one-half to one mile distant, and all about one mile south of the cut-off. These deposits can be explained only in two ways. Either the ice extended upon the highlands one mile south of the cut-off (which is the more probable hypothesis) or water stood at that level while the ice-front was in the vicinity. As to the causes which might be supposed to have kept the water at that level, I will speak a little later.

Recurring now to the deposits south of Bainbridge, their true significance can be made to appear. Beech Flats is evidently a still-water deposit, for it is nearly level topped, slanting but gently to the south; it penetrates the side valleys for two miles south of the moraine-like deposits; it is of fine material like the loess; it is of considerable depth, being eroded by small streams in many places so as to show from ten to twenty feet in depth of homogeneous material; it ceases rather suddenly on the southern side, though there is no obstruction in that direction. No such deposit could have taken place in that position if there had been a ready outlet to the water down the valley of Brush Creek, for the valley does not materially contract in dimensions towards the south, and the descent, all the way to the Ohio River, is rather rapid, being not *less than from six to ten feet to the mile*. It follows that if the valley

had been open, a body of water large enough to have produced this loess deposit of which Beech Flats is constituted would have produced a torrent down Brush Creek of sufficient rapidity and size to have transported gravel and pebbles far down its course, forming terraces in that stream as in the other streams emerging from the glacial boundary. But there are no such terraces. In going three times over the field for several miles to the south, I looked in vain for any granitic pebbles along the stream.

Putting the facts connected with Beech Flats with those connected with the Paint Creek cut-off, near Chillicothe, there would seem to be but one adequate explanation, namely, the production of slack water at a level from 900 to 1,000 feet above tide by some such temporary obstruction as I have supposed in the Cincinnati ice-dam. This would permit a level-topped deposit of fine material immediately in front of the moraine, such as exists in Beech Flats, and would prevent the transportation of overwash gravel down the valley open in ordinary circumstances along Brush Creek. That at that time no line of drainage could have been opened through the Paint Creek cut-off is also evident from the facts presented. The main work of erosion through the Paint Creek cut-off, indeed, may have been, and probably already had been, accomplished in preglacial times by small streams. But the creek itself had doubtless continued in its original channel until the ice from the north reached Slate Mills, when the obstructed water must have begun pouring through the cut-off, and must have rapidly completed the work of erosion already well advanced by the work of the smaller streams. But if, as we have seen reason to believe, the ice continued to extend until it had passed the cut-off, so as to deposit the striated pebbles found on the farm of Mr. Long, one mile south of the cut-off, the outlet through this channel must for a time have been obstructed, and as there is no other lower place till reaching Cynthiana, the drainage ordinarily passing through the mouth of Paint Creek was turned into Brush Creek, when, if the way had been open, there would have been produced a torrent as in other valleys similarly situated.

But if one is not willing to grant that the granitic and striated pebbles to the south of the cut-off were deposited by an extension of glacial ice, but would maintain that these were carried thither by floating ice, he has still the problem of accounting for standing water at that level (not less than 1,000 feet above tide) on the Scioto side of the projecting table land as well as on the Paint Creek side. These deposits one mile to the west of Mr. Long's farm (on the southeast side of Paint Creek Valley and 250 feet above it) and similar deposits farther up the valley might at first seem to be the result of the more local ice-dam at the mouth of Paint Creek. But when considered in connection with the similar gravel deposits one-half mile to the east, in the watershed drained by Rolston Creek, which empties into Paint Creek below the cut-off, it seems more likely that both of them are to be connected with

the same cause, and that this cause is the one which produced the slac water in which Beech Flats were formed. Thus we seem to have in this fortunate combination a crucial test of the hypothesis in question in which the conditions are met in every important particular.

The theory is further confirmed by the fact that the lower portion of Paint Creek is so situated with reference to the glacial boundary that when the ice-front at this point had withdrawn but two or three miles, and it would very likely do contemporaneously with the withdrawal of ice from Kentucky, an ample outlet for glacial drainage would be opened into the Scioto 200 feet lower than the surface of the moraine between Paint and Brush Creeks; so that the natural necessity for a glacial outlet down Brush Creek would exist only so long as the ice closed up the mouth of Paint Creek. Just as soon, therefore, as the ice had retreated from the Kentucky hills south of Cincinnati so as to raise the blockade, and reopened the channel of the Ohio, it would doubtless also have retreated from the mouth of Paint Creek, and the line of glacial drainage through that into the Scioto and thence down the reopened Ohio would have been reestablished.

A theory which will so naturally account for so complicated a set of facts as these is well-nigh proved by this single instance. The only competing theory possible is that of a general subsidence of the country producing the same water level above Cincinnati which the ice-dam is supposed to have done. But this theory lacks such positive evidence as we have for the glacial dam at Cincinnati, and besides, it is not probable that a general depression of the country such as would produce still water at the head of Brush Creek would be of such short duration as is implied by the facts connected with this deposit, since any such general cause of obstruction would have been likely to reverse its action slowly, and so would have given time for the formation of numerous benches on the interior of the deposit toward the ice, whereas the terrace on that side is even more abrupt than on the other.

Freshness of the vegetable remains near the glacial margin.—The question of the occurrence of such an immense interglacial period as is implied in attributing the high level terraces just mentioned, as well as the glacial deposits in Boone County, Kentucky, to a first glacial epoch entirely distinct from that which covered the most of the area marked as glaciated, can not be settled without considering carefully the deposits of wood and peat found near the margin in widely separated localities all along the line.

One of the most instructive localities in which to study these deposits is in the region included in southern Montgomery and Butler Counties, Ohio. These deposits were first described by Prof. Orton, of the Ohio survey, in 1870.¹

The most considerable deposit is found near Germantown, on Twin Creek, in Montgomery County, about thirty miles north of Cincinnati.

¹ Am. Jour. Sci., 2d ser., vol. 50, 1870, pp. 54-57.



SECTION OF PEAT AND DRIFT, GERMANTOWN, OHIO.

1

a sharp angle of the stream there is exposed a perpendicular drift 95 feet in height. Underneath this is a deposit of peat as much as 14 feet thick. The upper portions of the peat "contain undecomposed sphagnum mosses, grasses, and sedges." Both the stratum of peat and the clayey till above contain "abundant fragments of coniferous wood, which in many instances can be identified as red cedar (*Juniperus virginianus*)."

(For the structure of the bank see Plate I.) The composition of the drift deposit above the peat is as follows: Immediately above the peat there is from fifteen to twenty-five feet of true till which has no sign of stratification, and abounds in striated stones. Above this occurs a band about ten feet thick of stratified material composed of coarse gravel and a good deal of fine sand. Above this to the top of the deposit is again true till, with, however, an occasional pocket or thin layer of stratified material. But, both up the stream and down it, the cut terminates to appearance in vast gravel beds and together. Down the stream the stratum of peat rises so as finally to come in contact with the band of stratified material mentioned, the intervening till meanwhile gradually thinning out beneath them. The appearance is that of a saucer-shaped deposit of which as would form in a kettle-hole, and which was subsequently covered over with the advance of the glacier.

Therefore it is necessary to interpret these facts as indicating two distinct glacial ages or not will naturally be a matter open to discussion.

That the facts indicate a somewhat prolonged interval between the first advance of the ice over the region and the second, can hardly be denied, for the peat is clearly enough between two glacial periods. But it may be well questioned whether an interval of a few years would not suffice for the accumulation of the peat and growth of the large cedar trees which, without doubt, flourished in the region immediately in front of the readvancing ice, and were suddenly overwhelmed by it. At any rate, the other localities where fragments of wood are found imbedded in the till would show that there was not any great difference either in the conditions or the time between the first and second advances of the ice. Some of these other facts now be noted.

Most extensive exposures of till containing woody fragments occur in Butler County, Ohio, a few miles southwest of the deposit described above. One of these, near Darrrtown, on Four Mile Creek, has been spoken of on page 63. Upon reference to the description of the course of events would seem to have been as follows: After a retreat of the ice occurred, during which, for a short time, the ice was active in depositing material over the lower stratum of till, there was a readvance in which a vast mass of unsorted material was piled along over the stratified stratum without disturbing it. At Darrrtown, in the bank described in the preceding paragraph, I discovered as many as four such marks of successive advances.

II. 58—7

and retreats. Pl. VIII shows a section of till on a tributary of Four Mile Creek, near Oxford, Butler County, a few miles only from Darrtown. In this the unstratified character of the deposit is sufficiently manifest, and a piece of wood well preserved is seen projecting from the perpendicular exposure of the bank. This is about forty feet below the surface, and is where no land slide could have occurred. Equally good sections were afterwards seen in the same county on Aunt Ann's Run, near the city of Hamilton.

The wood in the instances next mentioned is found still nearer the glacial margin and they are of such a character and so numerous as to connect the previous instances with a glacial movement extending to very near the extreme margin of any signs of the direct action of glacial ice.

It is reported to me that a sycamore log was found at Morgantown, Morgan County, Indiana, 30 feet below the surface. This is, however, in a stratified deposit, but one which was evidently formed in connection with the last stages of the glacial period at that point. It is one-quarter of a mile back from the little creek running through the village, and the glacial limit is but a few miles south, on the higher lands of Brown County.

Near Seymour, Jackson County, Indiana, logs of wood are reported as occasionally found in digging wells in the village at a depth of 20 feet below the surface. Seymour is on a glacial terrace in the line of Collett's glacial stream, which was supposed to flow just east of the highlands in Brown County, and southward towards Jeffersonville. The wide terrace on which Seymour stands, and in which the logs are found, is about sixty feet above the present bed of the east fork of White River, running through the place. Black walnut logs are also mined from the banks of the river in low water. This instance is probably not decisive of the age of the buried wood, as the terrace may be the product of the so-called second glacial period. All agree that one of the later forward movements of ice in the interior came down as far as the northern border of Brown County.¹

Other most decisive instances occur in Bigger township, in the southeastern corner of Jennings County, Indiana. Here, as already said,² wood occurs in one well 12 feet deep in true till, while near by wood was reported to me as found 30 feet below the surface in a well that failed to reach the rock at that depth. This is on as high land as there is in that region, and is about ten miles north of Madison, on the Ohio River, and about five hundred feet above it; and the signs of glaciation are abundant over the whole region. The well reported by Professor Borden,³ at Paris Crossing, in Jennings County, as containing wood in blue drift clay 40 feet below the surface, is about twelve miles southwest of

¹ Preliminary paper on the Terminal Moraine of the Second Glacial Epoch by T. C. Chamberlin, Third Annual Rept. U. S. Geol. Survey, 1883, p. 333.

² See page 67.

³ Seventh Annual Report Geological Survey, Indiana, for 1875 (1876), p. 172.



SECTION OF TILL SHOWING WOOD, ONE MILE SOUTH OF OXFORD, BUTLER COUNTY, OHIO.

ng place. That at Milan, with muck and wood 54 feet down evidently the true till of the region, is near the summit of mty, Indiana, and is as far south as Cincinnati, and about as northwest from the river.

lton County, Ohio, Col. Charles Whittlesey reports thirty-five ining muck beds, leaves, or timber, from 300 to 500 feet above river.¹ That at New Burlington is certainly in till.

land County, Ohio, Prof. Orton reports many cases of the of such vegetable deposits. In the village of Marshall alls out of twenty reached a stratum of vegetable matter, with nches, roots, and trunks of trees." Marshall is on the very ciation. Similar instances were reported to me in the south- Highland County and in Clermont County.

County, near Lattas, Mr. J. M. Connell reported to me find- n a well on his farm. This is situated very near the extreme cial action, and is where it could not have been brought into water action. Mr. Connell's farm is 425 feet above the val- kfort, two miles to the north, and 525 feet above the valley oto River at Chillicothe, 10 miles to the east. The till is in great quantities against and upon the margin of the rocky re facing the north. The well described was in this marginal re highest land, and passed through 12 feet of yellow clay, gh three or four feet of blue clay, then 10 feet of yellow clay, l for five feet. About thirteen feet below the surface there a log of wood three or four feet long, and about three inches r. This was in blue clay, and was accompanied with traces

mitted to mention many other places where wood is reported e perhaps preglacial channels serving as outlets to the south ing torrents, and which may have been transported a long om their native place. One such was reported to me in the lacoon Creek in Granville, Licking County, Ohio, and but a rom the glaciated border. This was found 94 feet below e of the terrace, which would bring it about forty feet below t bed of the stream. A few miles farther up in this same cedar logs were formerly found in great numbers beneath rred were the glacial terraces along the valley; and the so fresh that a flourishing business was for awhile carried rfacturing them into pails. Red cedar is not found growing ion now, and the logs were evidently of the same period e described as found in true glacial till in Butler County.² llett reports that all through southwestern Indiana there are . 60 to 120 feet below the surface, peat, muck, rotted stumps, anches, and leaves of trees, and that these accumulations

athsonian Contributions for 1869, pp. 13, 14.

² See above, p. 63.

sometimes occur through a thickness of from two to twenty feet. One mile west of Switz City, in Greene County, Indiana, a hickory log was reported to me as found 20 feet below the surface, but according to my observations, this was a short distance outside of the glaciated limit, and may have been of recent origin.

SUMMARY.

It will be profitable at this point to take a rapid survey of the facts bearing on the theory of a glacial dam at Cincinnati.

(1) The deposits in Kentucky south of the Ohio River, in Boone and Campbell Counties, seem to be such that only glacial ice could have deposited them. This being granted, the question then comes whether this extension of glacial ice took place before or after the erosion of the trough of the Ohio River. Bearing on this question we note that—

(2) The freshness of the glacial deposits in Hamilton County immediately north of the river, together with the perfectly preserved specimens of wood just enumerated from till in Jefferson and Ripley counties Indiana, and in Butler, Hamilton, Clermont, and Highland Counties Ohio, would seem to indicate that they belonged to a period much less remote than that when the Ohio was flowing in a rocky bed from three to four hundred feet higher than that now occupied. And it is scarcely probable that a second general glacial period, separated so far from the first, would be so nearly coincident in extent with the first as it must have been if the deposits south of the river belong to the earlier, and those north of the river to the later, period.

(3) The high terraces on the Big Sandy, in Teazes Valley, at the junction of the Kanawha and Elk Rivers, and near Morgantown, Fairmont, and Clarksburgh, in West Virginia, and at Carmichaels on the Monongahela, in Pennsylvania, can with difficulty be assigned to that remote period when the streams in those valleys flowed over rocky beds at heights corresponding to the height of the terraces. Slack water of some kind must be supposed to account for their evidently recent origin.

(4) The fine character of the sediment constituting the overwash in front of the moraine at the head of Baker's Fork of Brush Creek, in Pike County, Ohio, indicates a body of still water there at a height corresponding to that of the supposed Cincinnati dam. The absence of terraces, and indeed of any northern drift along the lower portions of Brush Creek, is additional proof of the same condition of things.

(5) Many of the high level terraces in the upper Ohio and its tributaries may be but remnants of river beds when the rocky bottom was at that level. But, since some of them were as evidently due to slack water deposition, when floating ice was abundant, simply considering them in themselves, it would remain to choose between two theories as to the cause of the slack water. The ice-dam theory has a rival in that of the general submergence of the Alleghany plateau to a depth of a thou-

sand feet or more. This has against it the enormous amount of change implied. It is an inordinate cause to introduce to account for so small a result. Furthermore, according to Prof. Lesley, there are not any corresponding terrace remnants on the east side of the Alleghanies, as there should be on this theory. Still, this is a point to be more fully investigated. The deposits of gravel and pebbles in the valley of the upper Potomac above Cumberland without much doubt mark former levels of the river bed and do not imply a submergence. I have not seen any definite descriptions of deposits farther south corresponding to these still-water deposits which I have attributed to the obstruction by the Cincinnati ice dam.

As the case now stands in my own mind, both the theory of continental depression and that of such an enormous period between two nearly contemporaneous fields of successive glaciation as is implied in attributing the deposits south of the Ohio and the high level terraces of the upper Ohio to a glacial period when the rivers flowed in rocky beds of corresponding height, must give place to the simpler theory that the ice, which all admit extended at no very distant date to the north bank of the Ohio for a distance of 50 miles, also extended at that time a few miles farther, and temporarily obstructed the channel, forming thus an ice dam of about five hundred and fifty or six hundred feet in height.

On this supposition, so natural in itself, all the facts are easily explainable. So confident have I become in the reality of this dam that I have not hesitated to use it as a means of putting myself in the line of discovering other facts which are the natural consequence of this. Many of the facts enumerated in this paper (as, for example, those connected with the headwaters of Brush Creek) were thus discovered. It was reasoned that they must exist from the nature of the supposition; and upon examination in proper localities it was found that they did exist according to previous calculation. I need not say that such experience is the most convincing proof of a theory.

THE LOESS AND ITS RELATION TO THE GLACIAL DRIFT.

A striking characteristic of the glacial deposits in southern Illinois, Indiana, and Ohio is that they are overlaid, to a greater or less extent, by a very fine deposit almost devoid of grit and wholly free from gravel. Near the Missouri and Mississippi Rivers this is of great extent, sometimes being as deep as 100 feet, and being of such texture that wells dug in it to that distance will stand for years without curbing. There seems to be no signs of stratification in this deposit, and its origin is a question hotly disputed, some writers, like Richtofen, Clarence King, and Pumpelly maintaining that it is the accumulation of dust which in the course of ages has been brought along by the wind.

But the more general opinion is that it is a water deposit, though upon that theory the absence of stratification and of the remains of *shell* is difficult to explain. In southwestern Iowa Prof. J. E. Todd &

me to a fresh section fifteen or twenty miles back from the Missouri River and several hundred feet above it, where a blanket of loess about twenty feet in thickness rested unconformably on irregular deposits of till, while near the junction of the loess and the till a stratum, a foot or more in thickness, contained many fragments of carbonized or half-decayed wood.

In my recent investigations I have kept in mind these problems concerning loess, but I can not say that very much light is shed upon them by my observations. Their whole relation to the glacial deposits throughout the region I have more particularly investigated is to me very perplexing.

In the first place, there seems to be no material difference between the loess covering the hills in Perry County, Missouri, entirely outside the glaciated region, and that superimposed upon the glacial deposits of Randolph and Jackson Counties, upon the opposite side of the river, in Illinois. The deposits upon the high lands of Perry County would be ordinarily and reasonably reckoned residuary clays, resulting from the decomposition of the limestone rocks upon which the deposit rests. Yet a chemical analysis fails to reveal any essential difference between the deposit in that place and that which rests upon the surface everywhere in southern Illinois. A partial analysis of two specimens taken from a cut near Perryville, Perry County, Missouri, 10 miles back from the river, and about three hundred feet above it, where the loess is about ten feet deep, gives the following results:

First specimen, 2 feet below the surface:	Per cent.
CO ₂	.061
CaO.....	.164
MgO.....	.264
Second specimen, 5 feet below the surface:	
CO ₂	.087
CaO.....	.237
MgO.....	.201

The next three specimens are taken from a cut in Randolph County, Illinois, several miles east of Chester. The cut is about twenty-five feet deep, and for the first 10 feet is without much grit and perfectly free from gravel; but gradually it merges into a deposit having every characteristic of true till. Three specimens of soil were taken from this cut, of which the first was near the surface, the second 10 feet lower, and the third 23 feet lower still. The following are the determinations of the same elements sought for in the preceding specimens from Missouri:¹

First specimen, near the surface:	Per cent.
CO ₂	.184
CaO.....	.257
MgO.....	.203

¹ These determinations were made by Mr. W. C. Metcalf, who accompanied me in this portion of the field.

Second specimen, 10 feet below the surface :

CO ₂	.101
CaO	.207
MgO.....	.128

Third specimen, 23 feet below the surface :

CO ₂	.149
CaO	.347
MgO.....	.192

The uniformity of composition in these specimens is certainly remarkable, as is the small amount of carbonic dioxide in each, being in no case as much as one-quarter of 1 per cent. In several specimens, however, from other places in southern Illinois a marked increase in carbonic dioxide was found in the lower portions of the deposits. For example, near Phillipstown, White County, a specimen from the fine soil near the surface shows but 0.039 per cent, while that from the till underneath gives 5.792 per cent of CO₂. In another cut in the same town the specimen from three feet below the surface yields no CO₂, while that from 10 feet yielded 7.029 per cent. Again in Heralds Prairie township, in the same county, a specimen from three feet below the surface, which is entirely free from gravel, yields 0.018 per cent of CO₂, while one four feet lower in what is noted as true till yields 6.007 per cent of CO₂. Again, in a cut three miles south of New Harmony, Posey County, Indiana, near the extreme limit of glaciation, the upper specimen, from two feet below the surface, yields 0.229 per cent, while that from 10 feet lower yields 6.032 per cent of CO₂.

The absence of any sharp line of demarkation between the loess and the till has also been both unexpected and puzzling. In oft-repeated instances the upper portion of a cut revealed several feet of loess entirely free from gravel, while, a few feet below, the till was unmistakable in its character and for two or three feet between, the character of the material was intermediate between that of loess and till. This occurred so often in both southern Illinois and Indiana that it may be set down as the prevailing characteristic. Over the southeastern part of Indiana there is a marked diminution in the amount of this superficial covering of loess. Still, it is nearly everywhere present. Over these counties there are extensive portions of the country occupying the summit of land, which is so level that drainage is extremely difficult. A few feet at the bottom appears to be compact till with granitic pebbles and scratched stones, while the surface and a few feet below is a light-colored loess.

Going still farther east, to Ohio, the phenomena are quite similar to those in the southeastern counties of Indiana (see above, p. 65 et seq.).

In Jackson County, Indiana, and farther west, near the sandstone knobs, the superficial deposit corresponding to the loess is a very fine sand, peculiarly favorable for the growing of melons. This would seem, evidently enough, to be a wind deposit. There is nothing corresponding to the loess in northern Ohio, so far as I know.

Considering the loess merely by itself, so far as it has come under my

observation, it would seem to be largely a residuary clay, and would most readily be accounted for by supposing a depression in the Mississippi Valley of several hundred feet after the continental glacier had attained its extreme limit, and then retreated to about the line marked by President Chamberlin as the limit of the ice during the second glacial epoch. Such an interglacial sea would have had poured into it the finer material washed down from the more northern regions, which would settle unconformably upon the older glacial deposits below. But the complete application of this theory of depression would involve so great changes in the more western and northern portions of the Mississippi Valley that it is doubtful to my mind whether it is tenable. Many of the phenomena of the loess may be accounted for, perhaps, by mere local causes. Temporary lakes may have been formed by slight orographic changes in different places. Over some of the extensive prairies of southern Illinois the direct wash from the melting ice to the north may have spread a film of fine material over the whole region to the south. Again, the winds may have had a considerable share in transporting this fine material before vegetation had advanced to cover the region from which the ice had recently retreated.

Professor Orton, anticipating Darwin's book on worms, many years ago suggested, in reference to the deposits in Highland, Brown, and Clermont Counties, Ohio, that the fine material had been brought to the surface through the agency of worms and other burrowing animals. President Chamberlin had also suggested this explanation for portions of the field. Such an explanation would seem the more reasonable over the regions mentioned in Ohio and southeastern Indiana, because of the comparative thinness of the deposit. The indefiniteness of the line of demarkation between the loess and the till over so wide a portion of the region would also favor the same view, except that frequently the depth of the loess is so great as to render such agencies insufficient. Still, perhaps the wind may in many instances have increased the depth.

GOLD NEAR THE GLACIAL MARGIN.

A few words should be said respecting the frequent discovery of gold near the glacial margin, since it is so often the cause of serious delusion. The whole region covered by my special investigations and lying west of the Blue Ridge in Pennsylvania, is covered with stratified deposits of the Upper Silurian, Devonian, and Carboniferous ages. So little disturbed are they that it would be hopeless to look for gold in them. The natural explanation, then, of finding gold anywhere in this region would be that it was a part of the glacial transportation from the granitic region to the north. I soon learned from experience that the gold diggings were sure to be located near the glacial margin, where it might be supposed that the till had been most weathered and washed, and which had, *presumably*, been skimmed from the disintegrated surface of the *northern rocks* on the first advance of the glacier over them. In this border

gold has been found frequently in quantities to repay a moderate expenditure in washing the gravel, but never in large quantities. I found such deposits in Brown County, Indiana (and indeed in all the southeastern counties of Indiana), in Brown, Clermont, Licking, and Knox Counties, Ohio, and in Lycoming County, Pennsylvania. In all cases these deposits are within the glacial boundary, and are near the glaciated margin.

The irregular and serrate character of the southern boundary of the glaciated region, along which these gold deposits are found, led Dr. Sutton¹ to speculate from false data as to the particular source of the gold. The relations of the gold deposits in Dearborn, Jennings, and Scott Counties, Indiana, to those in the northern part of Brown County, in the same State, are wholly accidental, arising from the irregularities in the glacial boundary. But, before that fact was discovered, it was natural to think them significant. Consequently an attempt was made by Dr. Sutton to locate the original gold accumulations to the far north by projecting the lines which were determined by the points in the southeastern counties and those in Brown County. I was more successful soon afterwards, when I had come to see the significance of the gold, in inferring from the reports of diggings what was the vicinity of the glacial margin in the localities named.

INTERGLACIAL MAN IN OHIO.

At the meeting of the Boston Society of Natural History for November 4, 1885, Prof. F. W. Putnam showed an implement chipped from a pebble of black flint, found by Dr. O. L. Metz in gravel 8 feet below the surface, in Madisonville, Ohio. This rude implement is about the same size and shape of one, made of the same material, found by Dr. C. C. Abbott in the Trenton, New Jersey, gravel, and is of special interest as the first one known to have been found in the glacial gravels of Ohio. The announcement of this discovery, coupled with a letter from Dr. Metz, saying that he had since found another such implement at Loveland, led me to visit the localities to see their relation to the glacial deposits of the region. The following are the results:

Madisonville is situated 11 miles northeast of Cincinnati, in the depression of a preglacial valley connecting the Little Miami River with Mill Creek, about 5 miles back from the Ohio. The Little Miami joins the Ohio some miles above Cincinnati, while Mill Creek joins it just below the city. The general height of the hills in that vicinity above the river is from 400 to 500 feet. But the hills just north of Cincinnati are separated from the general elevation further back by the depression referred to, in which Madisonville is situated.

The depression is from one to two miles wide and about five miles long from one stream to the other, and is occupied by a deposit of gravel,

¹ See abstract of paper on the gold-bearing drift of Indiana, *Proc. Am. Assoc. Adv. Sci.*, 30th (Cincinnati) meeting, 1881, p. 177.

sand, and loam, clearly enough belonging to the glacial-terrace epoch. The surface of this is generally level, and is about two hundred feet above the low-water mark in the Ohio. On the east side, towards the Little Miami River, at Red Bank, the gravel is rather coarse, containing pebbles, ranging from one to three or four inches, interstratified with sand, and underlaid near the river level with fine clay. There is here a thin covering of loess, or fine loam. On going westward this loess deposit increases in thickness, being at Madisonville, one mile west, about eight feet thick. Further west it is much deeper, and seems to take the place of the gravel entirely. At several railroad cuttings, "till," with scratched stones, appears underneath all.

Thus it appears that this cross-valley connecting Mill Creek with the Little Miami back of Avondale, Walnut Hills, and the Observatory was once much deeper than now, and has been filled with the deposits made when immense glacial floods were pouring down these two streams from the north. The Little Miami was a very important line of glacial drainage, as is shown by the extensive gravel terraces all

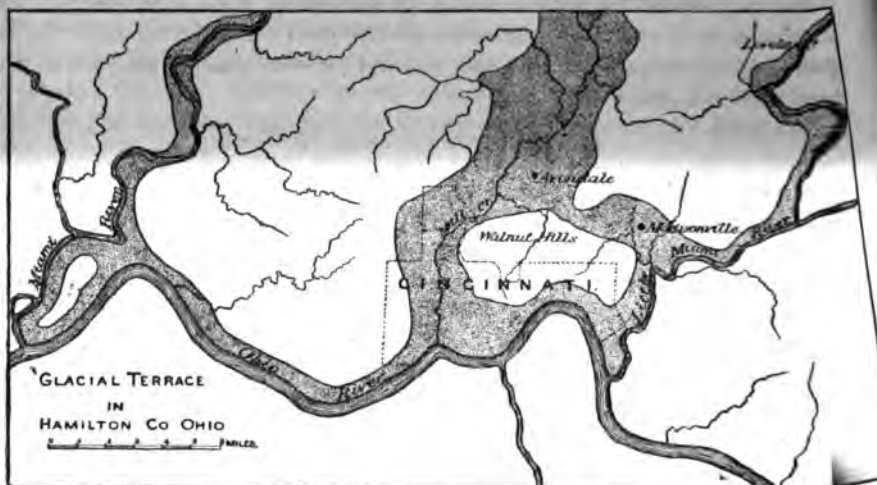


FIG. 10.—Map of Hamilton County, Ohio, showing situation of glacial terrace in which paleolith was formed.

along its course. The railroads resort to these terraces for ballast from long distances. The coarser material was naturally deposited near the direct line of drainage, where the current was strong. Naturally also back from the river towards Madisonville there is an increase of the fine deposit, or loess, which is particularly a still-water formation. There can thus be no doubt as to the true glacial character of the formation.

As to the implement, it is preserved in the Archaeological Museum in Cambridge, Massachusetts, where any one can examine it and compare it with similar ones from other parts of the world, and is of the true paleolithic type. It is not smoothed, but simply a rudely chipped,

pointed weapon, about three inches long. Dr. Metz found it in 1885, while digging a cistern. In making the excavation for this he penetrated the loess eight feet before reaching the gravel, and there, near the surface of the gravel, this implement was found. There was no chance for it to have been covered by a slide, for the plain is extensive and level topped, and there had evidently been no previous disturbance of the gravel.

Subsequently, in the spring of 1887, Dr. Metz found another paleolith in an excavation in a similar deposit near Loveland, Ohio. Loveland is also on the Little Miami River, about twenty miles above Madisonville. The river makes something of an elbow at this point, opening to the west. This space is occupied by a gravel terrace about fifty feet above the stream. The terrace is composed in places of very coarse material, resembling very much that of Trenton, New Jersey, where Dr. Abbott has found similar implements. The excavation is about one-quarter of a mile west of the river, near the residence of Judge Johnson. The section shows much coarser material near the surface than at the bottom. The material is largely of the limestones of the region, with perhaps ten per cent. of granitic pebbles. The limestone pebbles are partially rounded, but are largely oblong, some of them being from one to three feet in length. These abound for the upper 20 feet of the section on the east side towards the river. One granitic boulder was about two feet in diameter. On the west side of the cut, away from the river, mastodon bones were found, not long before, in a deposit of sand underlying the coarser gravel and pebbles. It was here, about thirty feet below the surface, that Dr. Metz found the paleolithic implement in question, which is an oblong stone about six inches long, four and one-half inches wide, chipped all around to an edge, and is, in the opinion of Dr. Metz and of Prof. H. W. Haynes, of Boston (a most competent judge), unquestionably of human manufacture. This, like the preceding implement, can be seen in company with Dr. Abbott's collection from Trenton, New Jersey, at Cambridge, Massachusetts.

Another similar discovery was made in 1886 at Medora, Jackson County, Indiana, by Mr. Hilborne T. Cresson, an experienced archæologist, of Philadelphia. Medora is upon the east fork of White River, near where it emerges from the glaciated region to enter the triangular unglaciated portion of southern Indiana, as shown upon our map. According to Mr. Cresson, a well-wrought paleolithic flint implement was found by him at this point in undisturbed gravel 11 feet below the surface, and about fifty feet above the flood-plain of the river, and in position such as to exclude its introduction, except in connection with the original deposit of the material. This implement is also in the Peabody Museum, Cambridge, Massachusetts.¹

A fourth discovery was made on the 27th of October, 1889, by Mr. W. C. Mills, at New Comerstown, Tuscarawas County, Ohio. This is a

¹ See proceedings of the Boston Society of Natural History, vol. 24, p. 160 et seq.

fine specimen of the true paleolithic type four inches long, two inches wide, and an inch and a half in thickness, tapering to a point, and in every respect of true paleolithic type, such as has characterized the discoveries in northern France and southern England. The material is a black flint, such as occurs in nodules in the "Lower Mercer Limestone" of the near vicinity. The implement has the waxy, glossy appearance which indicates considerable age, and was found by Mr. Mills in a gravel-pit from which the railroad has, for a long time, been at work obtaining ballast. Upon receiving information of this discovery, I visited the locality, and found, as I had surmised from Mr. Mill's description, that the gravel-pit at New Comerstown belongs to the glacial terrace of the Tuscarawas River Valley which I have described in the body of my report. The trough of the river is here about a mile in width, and the summit of this terrace 35 feet above the flood-plain. Mr. Mills found the implement in undisturbed strata of this terrace, 15 feet below its surface.

By those familiar with the subject these paleoliths will at once be recognized as among the most important archaeological discoveries yet made in America, ranking on a par with those of Dr. Abbott, of Trenton, New Jersey. They show that in the Mississippi Valley, as well as on the Atlantic coast, man was an inhabitant before the close of the glacial period.

GENERAL CONCLUSIONS.

On surveying the whole field of my investigations and limiting my conclusions mainly to what the facts there found would make necessary, the following would seem to have been the course of events:

From some center north of the great lakes snows accumulated until an ice flow to the south became necessary to dispose of the excess of the snow-fall over the annual melting power of the sun. This snow-fall was greater at some points than at others, so that there were separate sub-centers for the outflow of the glacial ice. Thus, in part, is to be explained the serrate character of the southern margin of the glaciated region, the ice projecting farthest opposite the larger accumulation of snow. The lower level of the larger valleys had also some effect upon the distance of the southern flow. There would seem to be no conclusive evidence that isothermal lines had anything to do in determining the irregularity of the southern margin. But they may have had some influence.

The ice as it moved onwards pushed on before it and incorporated into it much material that had been disintegrated by previous subaerial agencies, and also executed a large amount of mechanical erosion by its own force. This is evident both from the extensive fields still retaining the glacial grooves and scratches, and by the demonstrated mechanical character of much of the till. It is probable that the deposits near the margin are, more largely than those farther back, the *product of preglacial disintegration*. This would account for their

rally being more completely oxidized, and their consequent higher rate. The rate of the advance of the glacier probably can not be definitely determined by any facts accessible in this field.

Having advanced to its extreme southern limit, and the climate being ameliorated, the ice began slowly and irregularly to recede, occasionally readvancing to cover again ground from which it had temporarily withdrawn. In some instances, as where the buried forests are found, some scores or hundreds of years may have intervened between the retrocession and the advance over limited areas.

The formation of a terminal moraine at any point would depend upon one or three factors: First, upon how long the ice front remained stationary at a given point. Other things being equal, the longer the ice remained at a point the greater would be the accumulation there. For some reason, the ice front would seem to have been longer stationary along the southern coast of New England than at marginal points farther west, perhaps because the waters of the ocean there met it and retarded it from attaining its natural southern limit. In the interior it would seem that the ice retreated rather steadily over most of the area occupied, so that the material which otherwise would have been piled up in front as a terminal moraine is more uniformly spread over a wide margin, making up in breadth what it lacks in height.

During the time that the ice extended into Kentucky an ice dam was probably formed about 550 feet in height (that being the height of the glacier to the south), sufficient to set the water 300 feet over Pittsburgh. A long, crooked, narrow, slack-water lake is supposed to have continued long enough for considerable material to accumulate at various points above, where tributary streams, laden with sediment, joined the main body of water. The length of the continuance of this condition of things need not have been many hundred years.

The overlying loess in southern Illinois and Indiana, and the analogous formations over some of the counties of Ohio perhaps make it necessary to suppose a depression of that region soon after the beginning of the retreat of the ice from its extreme southern limit. This depression may also have extended to the Alleghanies, and so have had something to do in producing some of the effects attributed to the ice obstruction at Cincinnati.

In the more northern region, near the lakes, there are regions of stratified sand and gravel superimposed upon the till to a height of about 100 feet above Lake Erie, and at several lower levels towards the lake. These are evidently water deposits, and most likely bars formed a little distance from the shore when the water stood at that height. The material of these ridges is largely local. From the extent of these ridges and the character of the surrounding country it would seem that the water did not remain long at the several levels indicated by these deposits. There are no animal remains in the lake ridges, but wood is often found beneath, and especially to the south of them on the side away from

the lake. The theory has been suggested, and seems altogether probable, that the barrier holding this body of water at such a high level was the unmelted ice of the glacier, which naturally remained longest to the north and east, across the valleys of the Mohawk and St. Lawrence.

Upon the question of the time which has elapsed since the withdrawal of the ice it is as yet too early to express any confident opinion. So far as the facts go, however, they point to a moderate estimate. The freshness of the wood that is found beneath the deposits of till, the small amount of erosion, both in the river valleys and in the gorges below the numerous waterfalls, together with the small extent to which the till has in general been oxidized, all would indicate a brief period of post-glacial time when compared with the enormous lapse of time during which the Ohio was wearing its long trough from a little above the Mississippi to the headwaters of the Alleghany and the Monongahela.

Through all this distance of not less than 1,200 miles the stream has worn a channel about a mile in width and several hundred feet in depth. The prosecution of investigations concerning post-glacial chronology will be of great historic interest if, as would appear from the discoveries of Dr. Abbott at Trenton, N. J., and those of Dr. Metz at Madisonville and Loveland, Ohio, Mr. Cresson at Mentone, Ind., and Mr. Mills at New Comerstown, Ohio, man was on the continent before the glacial ice had withdrawn from the headwaters of the Delaware and Little Miami rivers. The facts brought to light in the present report will greatly aid in such calculations. The subject merits more careful study than has heretofore been devoted to it.

INDEX.

	Page.	
ier, dam formed by	17-18	Elk River, West Virginia, terraces on....
iver, table showing heights of		Georges Creek, Pennsylvania, terraces on.
ces on	27	Gilbert, G. K., cited on terraces of the Up-
on	30-31	per Ohio River district.....
ewing ancient level of.....	34	cited on oxbows of the Ohio River
River terraces, character of		tributaries
rial composing	28	cited on terraces of Ohio River tribu-
nd Monongahela Rivers, geo-		taries
al history of	35-37	Glacial boundary in Illinois
and Ohio River channels re-		Glacial boundary in Indiana
l by glacial deposits	57	Glacial boundary in Ohio, map showing..
r, Ky., terraces in	90	Glacial dam on the Ohio River
s, Pike County, Ohio, glacial		Glacial deposit in Ohio, depths of
on at	92-96	Glacial deposits between the Alleghany
l., terrace at	91	Mountains and the Mississippi
l., cited on bowlders in Maasa-		River
setts	51	Glacial margin, character of.....
River, terraces on	88	divergent views concerning
essor, sections from Indiana		Glacial striae in Pennsylvania
s given by	66, 67	Glacial striae on Alleghany Mountains,
the till, source of.....	50-52	Pennsylvania
cited on former drainage of		Glacial striation
ghany basin	34	Gold near the glacial margin.....
a preglacial outlet of Alle-		Gould, Dr., cited
ny River	57	Haynes, H. W., cited on paleolith found in
T. C., cited on the till	42	glacial deposits in Ohio
glacial deposits west of the		Ice dam on Ohio River.....
ghanies.....	58	Illinois, glacial boundary in
southern limit of glaciation		glacial deposits in
ndiana	98	Indiana, glacial boundary in
eory as to the origin of por-		glacial deposits in
s of the loess	104	Kentucky, glacial deposits in
Martyn, cited on river terraces		Lesley, J. P., cited on river terraces in
ennsylvania.....	24	Pennsylvania
oxbows on the Alleghany		Lewis, H. C., cited
er	30	cited on glacial striae in Pennsylvania.
reek, Pennsylvania, terraces		work on drift margin
.....	26-27	Loess, analyses
W., cited on average depth of		Loess deposits of the Mississippi Valley. 1
ial deposit in Ohio	44	Lyell, Chas., cited on Ohio River terraces.
e H., work on drift margin...	13	Man (interglacial) in Ohio.....
bowlders in the till	51	McGee, W. J., cited on loess deposits on
born T., found paleolithic im-		American rivers
ment in glacial deposits of Ohio	107	cited on terraces in West Virginia...
iver, geological history of....	43-44	Mergelen See, Switzerland, ice dam at....
in Ohio River	17-38, 76-101	Metcalf, W. C., acknowledgments to
, cited on transportation of		Metz, C. L., found interglacial paleoliths
lders	50-51	in Ohio
ho, glacial deposits near....	49	Milan, Ind., record of well at
, character of	14-15	Mills, W. C., found paleolith in glacial de-
ae of the Upper Mississippi..	19	posits in Ohio

	Page.		Page.
Mississippi (upper), driftless area of	19	Striae in Pennsylvania	40-41
Missouri, glacial deposits in	72-73	Striation, glacial	15-16
Monongahela River, table of heights of terraces on	25	Sutton, Geo., cited on glacial drift on Ohio River	17
oxbows on	31	Tenases Valley, West Virginia, river deposits at	86-88
terraces on	83-86	Terraces of lakes and rivers distinguished	20-22
Monongahela River terraces, character of material composing	28	Terraces of the Ohio River and its tributaries	20-38, 76-101
Monongahela and Alleghany Rivers, geological history of	35-37	table showing heights	23
Montours Run, Pennsylvania, terraces on	27	moraine-headed	23
Moraine-headed terraces on tributaries of upper Ohio	32-37	Terraces on Alleghany and Monongahela Rivers, heights of	28
Newberry, J. S., cited on glacial action in Ohio	43	character of material composing	28-31
cited on refilled trough of Alleghany River	57	Terraces on the Monongahela	83-84
New Jersey, glacial deposits in	55	Terraces on Elk River, West Virginia	88
New York, glacial deposits in	56-57	Terraces on Big Sandy River	
Nberlin artesian well, record of	47	Terraces in Bath County, Ky.	
Ohio and Alleghany River channels refilled by glacial deposits	57	Terraces at Bellevue, Pa.	
Ohio, glacial boundary in (map)	46	Till, mode of origin of	
glacial deposits in	59-63	summary of facts concerning	42
interglacial man in	105-108	distribution of	43
Ohio River, glacial dam on	76-101	character of material composing	45
Orton, Edward, cited on average depth of glacial deposits in Ohio	44	distribution in New England	52
cited on glacial action in Ohio	93, 96	regularity of distribution of	52
early theory of the origin of the loess	104	Todd, J. E., work on drift margin	
Oxbows or abandoned channels on tributaries of the Ohio	29-32	Topography of drift border as a determinant of extent and limit of ice margin	
Paris Crossing, Ind., record of well at	67	Upham, Warren, work on drift margin	
Parker, Pa., oxbow on Alleghany River near	30	cited on lenticular hills of New England	53, 54
Pennsylvania, glacial deposits in	55-56, 58-59	Vegetable deposits, perfect preservation not an evidence of recency of	55
Pocono Plateau, boulders on	51	Vegetable remains in the glacial deposits	49, 85, 86, 96-104
Putnam, F. W., found interglacial paleolith in Ohio	105	White, I. C., cited on river terraces in Pennsylvania	24
River channels in Ohio and Pennsylvania refilled by glacial deposits	57-58	cited on deposits on Monongahela River	29
River terraces and lake terraces discriminated	20-2	cited on terrace deposits on tributaries of the Monongahela	37
River terraces in Pennsylvania and Ohio	20-38	cited on terraces of the Monongahela River	76, 83, 84
Rocky River, Ohio, geological history of	44	cited on terrace at Bellevue Pa.	81
Salisbury, R. D., cited	14	cited on preservation of soft bowlders on Big Sandy River	88
work on drift margin	13	cited on lacustrine deposits on benches and valleys on the Monongahela	89-90
Shaler, N. S., cited on transportation of bowlders	50	Whittlesey, Chas., heights of Ohio rivers above tide shown in table prepared by	46
cited on origin of drumlins	53	Wright, G. F., cited on river terraces in Pennsylvania	24
Smock, John C., work on drift margin	13	Youghiogheny River, terraces on	26
Stevenson, J. J., cited on terraces of Ohio River tributaries	22		
cited on river terraces in Pennsylvania	24		
Striae on Alleghany Mountains, Pennsylvania	40		

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

EOLOGICAL SURVEY

No. 59



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

THE GABBROS

AND

SOCIATED ROCKS IN DELAWARE

BY

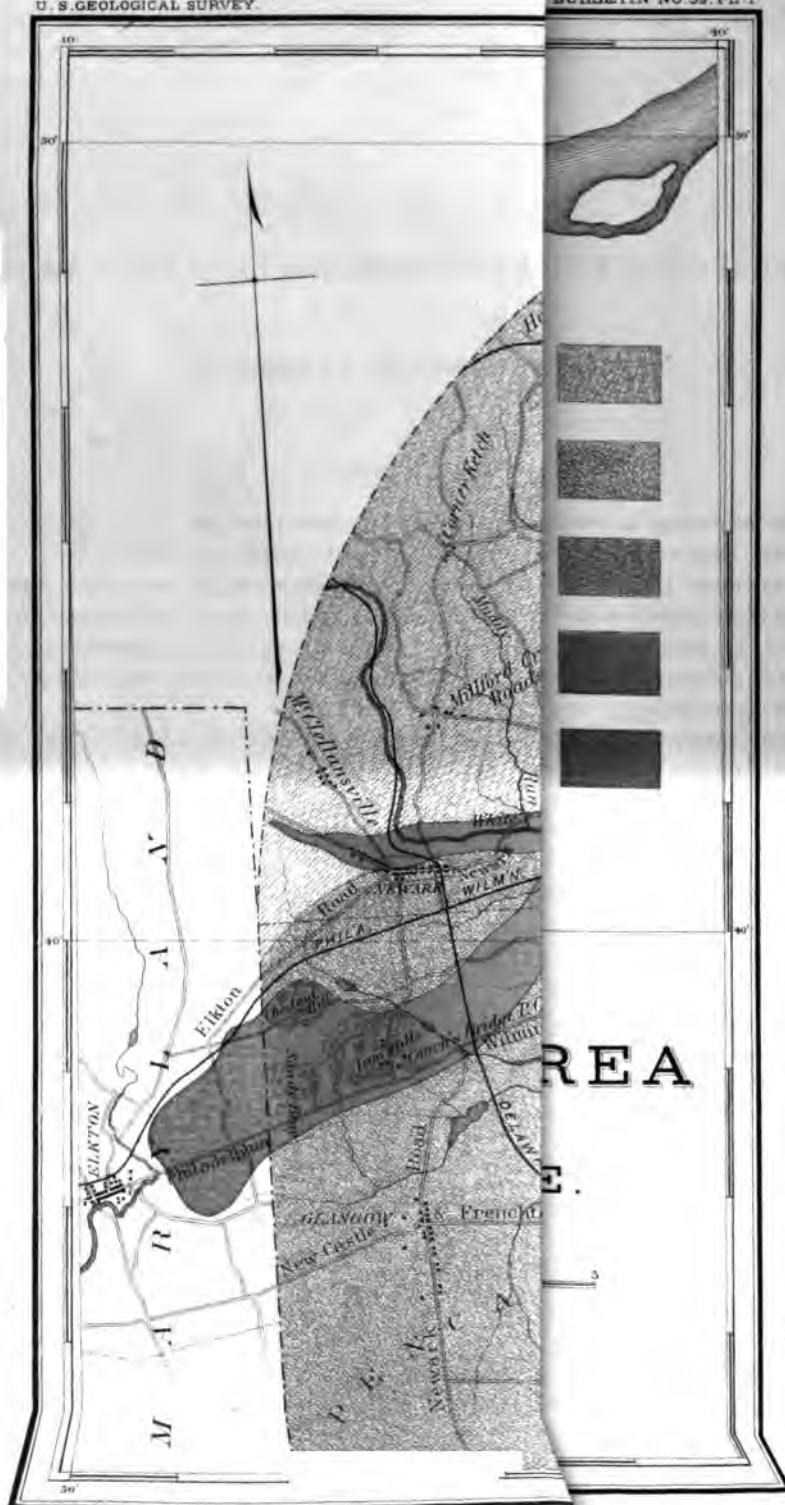
FREDERICK D. CHESTER



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890







THE GABBROS AND ASSOCIATED ROCKS IN DELAWARE.

By **FREDERICK D. CHESTER.**

INTRODUCTION.

The following investigation upon the gabbros and their associated rocks in Delaware has occupied my attention for over two years past, and has been treated thus in detail, first, because the massive gabbro is the most prominent formation in the northern part of the State; and second, because a thorough study of it embraces some interesting questions in petrography and their bearing upon structural phenomena of great magnitude.

In the order of treatment the petrography has preceded the discussion of structural phenomena, for the reason that many of the problems under the latter head must depend for their solution upon petrographical facts. In view of the magnitude and importance of the material under investigation, reflection upon the nature of the results herein set forth compels the confession of a certain timidity of statement in this paper. The evidence at hand has been carefully weighed and opinions have been recast, until the results embodied finally possess at least the virtue of having been patiently evolved.

It would be unjust to prior authorship not to take note of the admirable and exhaustive memoir of Dr. G. H. Williams¹ upon the Baltimore gabbros. So great is the similarity between these rocks and those of Delaware that our present descriptions must in some cases involve a repetition of the work of Dr. Williams. In another sense, however, the gabbros of Delaware merge into types so entirely distinct and exhibit phases of paramorphic change so novel, as to render the present results, perhaps, of some additional interest.

My thanks are especially due to Dr. Williams for much encouragement and assistance, and also to Prof. R. D. Irving and to Mr. Whitman Cross for the examination of thin sections involving difficult points.

¹The Gabbros and Associated Hornblende Rocks in the Neighborhood of Baltimore. Bull. U. S. Geol. Survey, No. 28. 1886.

GENERAL PETROGRAPHICAL CONSIDERATIONS.

The petrography of the Delaware traps is based upon an examination of numerous thin sections from all parts of a relatively small area, the form and extent of which are seen from the accompanying map. These sections show the different variations in our Delaware rocks, together with the various stages of paramorphic change from pyroxene to amphibole, so fully as to render additional material of no essential moment in establishing the conclusions adduced.

The Delaware traps, exclusive of the younger orthoclastic granites, may be designated by two terms, *gabbros* and *gabbro-diorites*.¹ These terms, however, have only the most general application, while a closer study reveals a variety of petrographical forms, not so much distinct in themselves as expressions of a wide variation from some arbitrary form which we call primary. This primary form is more clearly the common hypersthene-gabbro, or the so-called blue granite of the Delaware quarries. It is normally a finely granular mixture of basic plagioclase, hypersthene and diallage in nearly equal proportions, with accessory quartz, magnetite, apatite, hornblende, and biotite.

Reference to the following analytical table will make clear the lines of variation proceeding from this primary hypersthene-gabbro:

(A.) HYPERSTHENE-GABBRO. Plagioclase, hypersthene diallage, with accessory quartz, apatite, pyrite, magnetite, brown hornblende, biotite.	By addition of (original?) brown hornblende	(B.) GABBRO-DIORITE and HORNBLende GNEISS.
	By addition of biotite as an important constituent; quartz in large amount.	(C.) GABBRO-GRANITE.
	Highly feldspathic and quartzose, with a little hypersthene and much magnetite.	(D.) NORITE.
	By paramorphism of pyroxene to green hornblende (uralitic).	(E.) GABBRO-DIORITE. (Iron Hill)
	By addition of compact green hornblende, either paramorphic or original.	(F.) GABBRO-DIORITE and HORNBLende GNEISS.
		(G.) EPIDOTIC DIORITE.

feldspar to
epidote.

In considering the Delaware gabbros as a whole we might say that their chief distinguishing feature is their highly acidic character, due to the large admixture of quartz. This is at once evident to the most casual observer, who not only sees quartz as a prominent constituent

¹ This very convenient term has been used by Törnebohm and G. H. Williams to indicate transitional types of rocks between gabbro and diorite, and to all uralitic diorites of like origin.

by hand specimen, but who observes in the faces of the rock in great seams and segregated masses of the same. It has been noted that the rock which in a general sense we would regard as a norhypersthene-gabbro is a most unstable form, running on the one hand into a rock possessing strongly the character of a granite, and on the other into those distinctly dioritic. Quartz, which is found in such amounts in the fine-grained gabbros northeast of Wilmington, is present in but a small amount in the normal gabbro of which a number of types have been found. This more basic standard, however, is well maintained; on the other hand, the Delaware gabbros tend by a series of gradations to become more and more acidic from a gradual increase of quartz.

The last variation of gain in quartz is also characterized by an increase in the gradual gain of biotite, until, as in many of the Bellevue and other rocks, we have a type which is more properly a granite, with pyroxene as only an accessory constituent.

The presence of a brown dichroic hornblende as a very variable constituent of the hypersthene-gabbro is a fact of the greatest interest, since the gradual increase of this mineral from a mere trace to an amount sufficient to subordinate the pyroxene elements we are led to see an increase in a gradual transformation to a black, highly schistose, hornblende which, structurally and macroscopically, seems at first sight to have no genetic relationship with the gray, compact gabbro with which it is associated. Regarding this brown hornblende as original, as I believe we must from present data, we can attribute this change from gabbro to a diorite only to the result of an original variation in the character of the eruptive material.

The change, on the other hand, from gabbros to green hornblende which we have, to a large degree at least, the results of a paramorphic process affecting the pyroxene of the mother rock; the final product in this case being a perfectly compact, green hornblende, whether this is derived directly from the alteration of diorite, or, as when hypersthene is the primary substance, from the intermediate fibrous amphibole, as described by Lehmann and by Williams.

As we may affirm that the whole result of a deliberate study of an extensive series of thin sections has been to teach most emphatically the principle that apparently diverse types can in reality possess an intimate genetic relationship. It is also believed that the sooner this is realized the sooner geologists will be defended from many errors of generalization based upon structural data alone. Nearly every section in our series is a transition stage from one type to the other, and the more clearly defined forms, that no sharp lines can be drawn among the designations made. Those set forth in the accompanying list must be understood, are largely arbitrary, serving simply to indicate certain dominant tendencies in the line of variation.

It can not be otherwise than evident to the most casual observer that

many of our former theories respecting the metamorphic rocks are undergoing radical alteration since the microscope has taken such a prominent place in geological investigation. This is particularly true as regards that great class of schistose, amphibole rocks which, until quite recently, have been generally regarded as altered sediments.

But since the investigations of Lossen in the Harz, J. H. Kloos in the Black Forest in Baden, F. Becke at Langenlois, Lower Austria, Törnebohm in Sweden, Lehmann in Saxony, Teall and Phillips in England, Wadsworth, Irving, and Williams in this country, an entirely new field has been opened, and geologists are in a fair way to discriminate between crystallized sediments and metamorphosed igneous rocks. That highly foliated schists in many cases may have had an eruptive origin has already been demonstrated by a respectable body of workers, while what is more encouraging than all is the indication of future developments in this fertile field of research. The element of pressure which plays such an important role in the development of slaty cleavage in the sedimentary rocks and their derivatives must in the future be recognized in accounting for the secondary products of the massive traps, by producing great structural alterations, and possibly by inducing molecular rearrangements and consequent paramorphic changes.

HYPERSTHENE-GABBRO.¹

This is taken as the primary and typical form of the trappean series. In color, it varies from a dark bluish gray to a black; in texture, from one distinctly crystalline to one quite aphanitic. Macroscopically the rock appears to be a finely granular mixture of striated feldspar, bluish quartz, rounded grains of black highly metallic hypersthene and a small amount of foliated greenish diallage. Under the microscope the several mineral constituents present characters which render their determination satisfactory.

The *hypersthene* occurs in irregular grains, never in crystals, which vary in size from 1^{mm} to 7^{mm}, the majority approaching 4^{mm} to 5^{mm}, while others again are spreading branching individuals, which fill up the spaces between the plagioclase and inclose numerous rounded grains of the latter. The cleavage is well developed parallel to the prismatic face (∞P) and to the brachypinacoid ($\infty P \infty$).

The pleochroism of all sections is strong, offering a ready means of distinguishing this mineral from its associated diallage. Sections in which the double prismatic cleavage is well developed, and which, with concentrated polarized light, show a biaxial interference cross, show also strong yellow and reddish pleochroism. Other sections with powerful greenish and yellow pleochroism were found, with which

¹I have adopted the term *hypersthene-gabbro* in view of its use by Dr. G. H. Williams, yet it remains a question whether, in consideration of the acidic character of many of our true hypersthene-gabbros, the term *norite* might not better express the position which our rocks bear to those in Europe.

ally clear interference crosses could be obtained. It is evident from a that in these two cases we have sections respectively parallel to basal pinacoid (0P) and to the macropinacoid ($\infty P \bar{\infty}$), and thus the rhombic character of the mineral as well as the arrangement of pleochroic colors is well established.

The trichroism is as follows: a copper-red; b yellow; c green.

All prismatic sections extinguish parallel to the cleavage. A number of cleavage leaflets detached by a penknife from the prismatic face of a larger fragment gave the same parallel extinction, and the color of the ray, with a combination of the a and b rays for light vibrating at right angles to the cleavage.

The specific gravity of a number of these fragments, which, after examination with the microscope, were found to be pure, was determined by means of the Klein solution and found to be 3.38. This high specific gravity excludes the possibility that this mineral is bronzite.

The hypersthene seems to be entirely free of the brownish, leafy inclusions, so characteristic of many hypersthene, and also of the hypersthene in the Iron Hill rocks, but beautiful symmetrical needles or rods arranged parallel to the cleavage lines are common, associated with larger, lenticular, black inclusions either of magnetite or of titanite ore.

The *diallage* can sometimes be found in the coarser hand specimens as a grass-green mineral with an eminent parting parallel to the orthopinacoid and to the prismatic face. Under the microscope thin sections have a pale green color, and show no apparent pleochroism, while thicker cleavage fragments show only the slightest change of color on revolving the stage over the polarizer.

Most prismatic sections give high angles of extinction approaching 90°. Cleavage leaflets parallel to the orthopinacoid extinguish parallel to the prismatic cleavage lines as would be expected, and give with concentrated polarized light the characteristic single optic axis. The specific gravity of a number of microscopically pure fragments of this mineral was determined by means of the Klein solution. While the diallage pieces remained freely suspended in the solution a fragment of green hornblende was dropped in, which easily rose to the surface and floated. The specific gravity of the solution, and therefore of the diallage, was 3.24. The diallage contains the same inclusions as the hypersthene, i. e., opaque needles and grains of magnetite, with frequently included fragments of hornblende and grains of plagioclase.

The *feldspar* occurs as granular particles, which vary in size from .1^{mm} to .5^{mm} in diameter. They show a fine polysynthetic twinning, and have commonly two systems of striation approximately at right angles to each other, according to the well-known albite and periline laws. The feldspars show those irregularities of twinning characteristic of many gabbros, i. e., lack of parallelism of the twinning lamellæ, irregularity in the length of the same, and their frequent wedge-shaped

character, showing under crossed nicols a beautiful interlocking of individual lamellæ. The angles of extinction are invariably high, indicating a basic feldspar. The examination of cleavage fragments of the feldspar isolated from a typical gabbro gave angles of extinction answering to a more basic labradorite. The specific gravity of the same isolated feldspar was 2.689, confirming the optical determination.

The feldspar from a typical Brandywine gabbro was separated by means of the Thoulet solution by Mr. J. S. Diller in the petrographical laboratory of the U. S. Geological Survey, and analyzed by Mr. R. E. Riggs, with the following result:

SiO ₂ = silica	51.44
Al ₂ O ₃ = alumina	30.05
Fe ₂ O ₃ = ferric oxide (FeO not det.)	.96
CaO = lime	13.19
MgO = magnesia	trace.
Na ₂ O = soda	4.07
K ₂ O = potash	.21
Loss on ignition	.35
	100.27

Dried at 105° C.

This answers to the most basic member of the labradorite group and to a feldspar having the theoretical composition Ab₁ An₂.

An examination of a number of cleavage fragments extracted from the feldspars of many of the coarser gabbros will show these feldspars to vary somewhat, which we could scarcely expect to be otherwise, in view of the great variation in the character of the iron-bearing silicates and in the proportion of quartz. This is illustrated most forcibly in the case of the more acid biotite-bearing gabbros, rocks similar to those which elsewhere have been styled *norites*. A typical sample of this rock was also treated by Mr. Diller, and the feldspar separated in the usual way from the ferruginous silicates. An analysis of the feldspar gave the result shown below, in column I:

	I.	II.
SiO ₂ = silica	70.37	64.12
Al ₂ O ₃ = alumina	18.36	24.76
Fe ₂ O ₃ = ferric oxide (FeO not det.)	.58	.....
MnO = manganese oxide	trace.	.....
CaO = lime	5.08	5.44
MgO = magnesia	.04	.....
Na ₂ O = soda	4.32	5.68
K ₂ O = potash	.63	.....
H ₂ O = water	.45	.....
	99.83	100

Dried at 105° C.

Column II gives theoretical composition of a feldspar having the formula Ab₃ An₁, answering to oligoclase.

If in column I the .63 per cent. of potash be assumed as replacing some of the soda, the ratio between soda and lime becomes more accordant in I and II.

In Column I the excess of silica above that required to form the feldspar molecule is represented by quartz which this specimen is known to contain, but which could not easily be separated from the feldspar owing to the little difference in the specific gravity of the two minerals.

The small amount of iron present is undoubtedly represented by inclusions of magnetite dust, which all the feldspars contain. On the supposition that the small amount of water in the analysis represents some kaolin, the amount of alumina in the analysis is thus slightly abnormal, but this will be fully counteracted by the opposite tendency of foreign matter to lower the alumina percentage.

Neglecting these small amounts, and adding proportionately the excess of silica to the alumina, lime and soda in column I, we get a result nearly in accord with column II.

An optical examination of a number of cleavage leaflets detached by a penknife showed in all cases for sections parallel to $0P$, an extinction so nearly parallel to the twinning bands as to make the less basic character of the feldspar plain. Sections parallel to $\infty P \propto$ gave with reference to the cleavage an extinction angle of $+5^\circ$. The specific gravity of these fragments was 2.635.

Thus we are led to believe that the more acid biotite-bearing gabbros contain at least as an accessory constituent the species oligoclase. Upon the whole the facts seem to strengthen forcibly the presumption that as our gabbros become more acid the feldspars also assume the more acid types. We shall furthermore see as we proceed that the hornblendic gabbro-diorites have a tendency in the opposite direction, the feldspar in the Iron-Hill rocks being clearly anorthite.

Notwithstanding these variations, a notable fact is the uniformity of micro-structure observed in all the feldspars from one end of the belt to the other. They are quite similar to those found so characteristically in other gabbro-feldspars.

These consist largely of black opaque needles of clear definition and of remarkable straightness, which, as they become wider, show generally an oblique termination at each end.

These run into elongated prisms or columns of a brownish color, similarly truncated, the longer axis of which, however, seems to bear no constant ratio to the shorter; the longer ones passing into those with nearly rhombic section. With these we find again similarly shaped prisms and rhombic sections of a black color and highly metallic character. The dust-like particles which everywhere occur as cloudy patches near the center of the feldspar individuals or arranged in bands coincident with the twinning lamellæ are made up of the shorter needles which merge into mere specks, or again of extremely minute crystals or irregular particles of a black, metallic character.

All the inclusions show a definite arrangement in parallel systems, of which there are commonly four, though sometimes only three. Of these, two show an arrangement parallel to the edge $0P : \infty P \propto$ and to

the vertical axis. A section of triclinic feldspar, apparently parallel to the plane $\infty P \infty$, showed distinct basal cleavage, approximately parallel to which was a definite arrangement of needles; but the system containing the greatest number of inclusions was that forming an angle of 110° with the cleavage, i. e., nearly parallel to the vertical axis. Sections more or less parallel to OP show an arrangement nearly parallel to the twinning traces, with another at right angles to the same. These two systems are again crossed by two other sets, perpendicular to each other, and forming with the first two sets angles from 20° to 25° . The character and arrangement of these inclusions are best shown in Fig. 1.

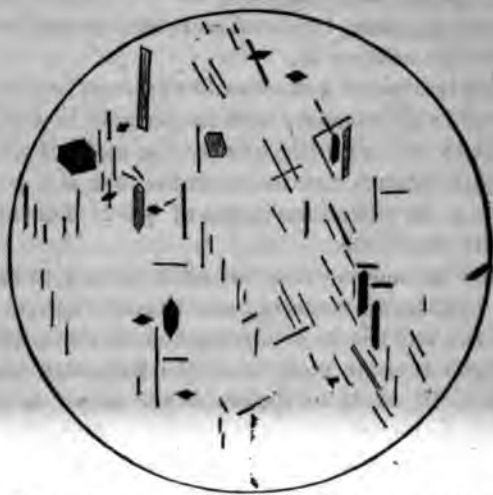


FIG. 1.—Inclusions within feldspar of hypersthene-gabbro.

Besides these, the feldspars are everywhere full of inclosures of foreign minerals, including rectangular crystals and dust-like particles of magnetite, well formed crystals of brown hornblende, and traces of biotite and pyroxene. In a few cases they contain very minute elliptical or elongated inclusions, with darkly defined borders, arranged linearly, without bubbles, and similar to gas pores. These are scarcely more than $.001^{\text{mm}}$ in diameter; associated with them are elliptical or greatly elongated tapering glass inclusions of a light brown, sometimes greenish color.

Magnetite is a very constant constituent of all the Delaware rocks, occurring frequently in such large amounts as to nearly or quite equal the pyroxene. It occurs as grains and dust-like particles from $.02$ to $.4^{\text{mm}}$ in diameter. With reflected light it is found associated in many cases with pyrite. It shows no decomposition into leucoxene, while a careful test gave only a slight reaction for titanium; hence it is probably a true magnetite.

Apatite occurs as prismatic and cross-sections, more generally as inclusions within the feldspars, also frequently within the hornblende and

the pyroxene. It contains in many cases an abundance of inclusions. These consist (a) of long transparent needles or prisms, frequently etched or corroded, at other times intact, centrally arranged parallel to the longest development of the inclosing substance; (b) black, opaque granules in elongated or irregular forms, such as so commonly occur within the feldspars, possibly ilmenite—these occur fully within the apatite, at other times partly or nearly penetrating one end or side of the same. In a few cases the apatite crystals are corroded, owing apparently to the caustic action of the feldspathic liquid. In one case at hand the apatite prism has been cut entirely across in the center by a fissure, and the space has been filled with feldspathic matter; a little below this is another fissure which has so far eaten into the crystal as nearly to bisect it.

Quartz occurs as an important element of all our rocks. In the thinnest sections it gives clear colors and feeble polarization, and is easily recognized by its want of cleavage and by the appearance with converging polarized light of a uniaxial interference figure. It generally contains groups and lines of extremely minute, darkly defined inclusions, entirely free from bubbles, possibly gas pores. Less frequently are found inclusions with quiescent or feebly moving bubbles, which do not disappear on heating the stage to nearly 100° C.

Brown hornblende and *biotite* occur as accessories, by the increase of which the hypersthene-gabbro (A) merges indistinctly on the one hand into the gabbro-diorite (B) and on the other into the gabbro-granite (C). See table, p. 8.

Garnet is found as an accessory in rare instances.

The true gabbros occur most abundantly along the Brandywine and upon all the roads leading out from Wilmington. In these localities admirable exposures are found in numerous quarries, and upon the particularly rocky picturesque slopes of the Brandywine Valley. Northwest of the city, however, the rocks become distinctly hornblendic and exhibit the various varieties of gabbro-diorite; northeast in Brandywine Hundred the rocks are associated with those acid forms which we have here for convenience termed gabbro-granites, although the two are never separated by any closely drawn structural lines.

GABBRO-DIORITE.

This name is given to those rocks which represent an extreme stage in the variation of the normal gabbro. Brown hornblende is known to occur as an accessory constituent of true gabbro, but some phases of the Delaware rocks show a peculiarly large admixture of this mineral, which becomes even of such importance as to more than equal the pyroxenic matter.

In extreme cases, again, the rock consists mainly of a mixture of brown hornblende and plagioclase, with pyroxene in but a trace. In

hort, we find every stage between the massive gabbro and a rock which is apparently a hornblende gneiss, making, as a consequence, a proper designation of the rocks difficult. Many types described under his head might strictly be placed with gabbros, others might be placed with hornblende gneisses or amphibolites, the rock possessing upon the whole a union of gabbro and diorite characters, for which reason the term gabbro-diorite is adopted only as a convenient one in the present instance, without attempting to add to the already burdened rock nomenclature. In hardly a single case, so far discovered, has the progress to more and more highly dioritic forms resulted in an entire absence of pyroxene; on the other hand, most of the forms presenting in the field all the characters of a hornblende gneiss or an amphibolite, contain pyroxene in such an amount as to make the rocks from microscopic examination no more strictly amphibolites than gabbros, but rather standing intermediate between the two, and thus the term in many cases is a natural one.

The extreme type of the gabbro-diorite is a black rock with a satiny lustre, showing generally a high degree of foliation; other transitional types show an obscure foliation, which serves to connect structurally the foregoing rocks with the massive gabbros. The hypersthene and the diallage of this rock are identical with the preceding. The feldspar gives somewhat higher angles of extinction, in the more extreme forms of this rock, approaching anorthite. It contains, however, the same characteristic inclusions and is apparently identical.

The hornblende occurs in large irregular grains. They have a greenish brown color in ordinary light and show powerful dichroic properties. Sections transverse to the vertical axis with the prismatic cleavage well developed give for the *a* ray a deep yellow, and for the *b* ray a deep brown with powerful absorption. Many longitudinal sections show no perceptible change of color or absorption upon revolving the stage over the polarizer; these are presumably sections approximately or quite parallel to the orthopinacoid ($\infty P \infty$), and give the color and absorption of the *b* and *c* rays. The mineral is therefore *dichroic* and of the variety known as *basaltic*.

The absorption formula is, as usual, $c = b > a$.

The mineral offers no notable characters except that it is unusually filled in many cases with inclusions of magnetite, which commonly in prismatic sections show an arrangement parallel to the cleavage. With these are found crystals of apatite, dust-like particles and symmetrical or irregularly shaped needles placed parallel to the vertical axis. A cleavage section of the brown hornblende parallel to the prismatic face gave an extinction angle c to c of 19° . Magnetite, pyrite, apatite, quartz and biotite occur as accessories of the gabbro-diorite (B, p. 8).

The relation which the hornblende bears to the pyroxene makes it probable that both consolidated out of a more or less molten magma; while it seems that in many cases the pyroxene consolidated first, it is

ally true that pyroxene individuals in many cases must have formed and hornblende particles, since grains of both hypersthene and green oxene, giving uniform optical orientation, are seen to inclose large small grains of brown hornblende. If we can accept the well known fact that hornblende and pyroxene are only two different crystalline forms of the same substance, determined by different physical conditions at the moment of consolidation, such as temperature and possibly rate of cooling, we might venture in this connection to suggest that the association of brown hornblende and pyroxene in these rocks might be accounted for by supposing these conditions to have been intermediate or oscillatory between those extremes, which in one case would produce a gabbro and in another a true diorite. We have already intimated that the gradual increase of brown hornblende proceeding from a massive rock was also accompanied by the gradual assumption of a more schistose structure. That this structural change has been induced by pressure is quite probable, hence there would seem to be some relationship between pressure and the relative proportion of hornblende to pyroxene. Could we have abundant proof of the alteration of pyroxene to compact brown hornblende, which is possible in view of the late studies of Dr. G. H. Williams on the rocks of the Cortlandt series¹ and Prof. R. D. Irving on the rocks of the northwest,² we would have a natural explanation, especially since these rocks present similar structural changes from massive to schistose forms.

In an article by the late Dr. G. W. Hawes³ we find a record of a rather doubtful instance of the alteration of pyroxene to compact brown hornblende in the occurrence of obscurely outlined inclosures of brown hornblende within pyroxene, the author remarking in support of his opinion that paramorphic alterations of this character might originate inwardly as well as outwardly. Thus in a like way do we find in the case of gabbro-diorites under consideration inclusions of hornblende with indistinct borders; but cases of this character unaccompanied by other evidences of paramorphism can hardly be considered as at all conclusive, consequently until further facts come to our notice we must regard this brown hornblende as original.

The distribution of the rocks of this class is by no means a definite one. Many of the exposures along the Brandywine show in places the perfect development of a foliated character, these rocks in turn being more or less hornblendic. The northern and northwestern parts of the city of Wilmington are covered by eminently or obscurely foliated rocks containing both pyroxene and brown hornblende, and the same is true of all the exposures along the Concord and Lancaster turnpikes leading out from the city. Roughly speaking, a line drawn from the Delaware station, on the Wilmington and Western Railroad, through

¹ Am. Jour. Sci., 3d series, vol. 28, 1884, pp. 259-268.

² Fifth Ann. Rep., U. S. Geol. Survey, 1885, pp. 175-242.

³ Am. Jour. Sci., 3d series, vol. 12, 1876, p. 136.

the northern limits of the city of Wilmington to the Brandywine will serve as a boundary north of which the outcrops are of black foliated rocks of this class. However distinct this area may at first sight seem to be, it is discovered that in all these rocks the genetic connection with the massive gray gabbros is steadily maintained, and into these the rocks of this area indistinctly merge. Since the most interesting feature of the brown hornblende gabbro-diorites is the position which they hold as connecting links between massive gabbros and highly schistose hornblende gneisses, it will be profitable to describe in order a series of slides which reveal most clearly these transformations.

SERIES ILLUSTRATING TRANSFORMATIONS.

Brandywine Creek, Wilmington.—A dark gray rock of uniform structure, massive, and possessing in the field the characters of a true gabbro. Consists mainly of hypersthene and plagioclase nearly equally developed, with a small amount of brown hornblende. Diallage in but a trace. The hypersthene as irregular branching individuals .5mm to .6mm, which fill up the spaces between the feldspar and which inclose minute grains of plagioclase. Garnets in rectangular, isotropic crystals of a pinkish color. Quartz in a few small grains. Magnetite, apatite. The feldspars partly clouded by dust inclusions, and numerous minute crystals of brown hornblende.

Wilmington City Reservoir.—Rock black, as massive boulders with obscure foliation, consists mostly of plagioclase with a small amount of hypersthene and a few particles of diallage; brown hornblende somewhat subordinate. Magnetite; apatite rare. The feldspars much clouded by dust inclusions. Quartz in small amount.

Henry Clay P. O. (Dupont's).—Rock black, with obscure foliation. Plagioclase the principal constituent, brown hornblende and hypersthene nearly equally represented. Diallage apparently absent. Quartz in several large grains. Magnetite; apatite.

Toll Gate, Kennot Turnpike.—Rock black, partly foliated, consists mostly of plagioclase with much quartz. The next element is brown hornblende with a little biotite; hypersthene in greatly subordinate amount. Diallage absent. Magnetite, pyrite, apatite.

Back of Old Alma House, Wilmington.—Rock black, thinly bedded, schistose, offering in the field all the characters of an amphibolite. The bisilicates somewhat in excess of the feldspar. Brown hornblende the chief bisilicate constituent, with less pyroxene represented about equally by hypersthene and diallage. Magnetite and apatite. This rock has the schistose character more strongly developed than the preceding, which is due to the relatively large proportion of bisilicate.

Kiemensie Station, Wilmington and Western Railroad.—A thinly bedded, highly foliated rock. Bisilicates considerably in excess of the feldspar, consisting of nearly equal parts of hypersthene and brown hornblende, and a small amount of characteristic diallage. Quartz in small amount. Magnetite scarce. The discovery of this rock is of particular interest, inasmuch as it forms a lenticular mass of highly foliated, thinly bedded hornblende rock between mica schists, along the north border of the main gabbro belt. A little farther north, and just below Brandywine Springs, is another outlying bed of gneiss, which is associated with a similar rock next to be described. Such facts as these enable us to assume with some probability that the outlying, lenticular masses of amphibolite within the mica schists are not to be separated in nature or in origin from the hornblende rocks of the larger area to the south.

Just Below Brandywine Springs Station.—A black, aphanitic rock. Under crossed nicols the ground mass is seen to be made of minute quartz and plagioclase grains, 1mm to 2mm in diameter, in which are porphyritically developed large and small hy-

persthene individuals, and numerous crystals of garnet, several millimeters across. The hypersthene was of a yellowish color, visibly but not eminently pleochroic, yellow and copper red with distinct prismatic cleavage, many of these sections showing with concentrated polarized light a biaxial cross. The garnet occurs as rectangular pieces of a pinkish color, entirely isotropic and full of characteristic inclusions enclosed by individuals of hypersthene. Brown hornblende in small amount. Magnetite rare. The feldspar highly basic, approaching anorthite.

Three miles north of Newport.—A black, semi-foliated rock, consisting of a nearly equal mixture of plagioclase and hornblende with but a trace of pyroxene, yet that little in well characterized fragments. The rock, therefore, represents the extreme stage of variation, and is properly a hornblende gneiss. The hornblende offers peculiarities; it is visibly trichroic, but not so strongly so as is characteristic of the green. The color of the c ray is a dark green; that of the b varies from a brown, quite like that of the basaltic variety to a greenish brown; and that of the a ray is a fine yellow. Absorption $c > b > a$. Sections approaching parallelism to the clinopinacoid gave extinction angles of about 15° . The hornblende, therefore, stands intermediate between the green and the brown, and is possibly indicative of an alteration of brown hornblende into the green variety. Magnetite in one large piece several millimeters across, full of beautiful included grains of plagioclase, also in smaller granules. The feldspars give high angles of extinction, and are probably either bytownite or anorthite.

Lancaster Pike and Wilmington and Northern Railroad.—Black, fine-grained rocks in association with coarser varieties; thinly bedded and schistose, although less strongly so than the intimately related coarser rocks, showing the feeble effects of pressure in developing a schistose structure in such aphanitic rocks, notwithstanding the large amount of hornblende. The principal constituent of the rocks is brown hornblende with somewhat less plagioclase. Hypersthene and green pyroxene in but small amount. Magnetite, pyrite, apatite.

GABBRO-GRANITE.

Another accessory constituent of the normal gabbro (A) is biotite, which gradually increases in amount so as nearly or quite to equal the pyroxene. This particular phase of the Delaware rocks, as already intimated, is furthermore accompanied by much quartz, so that the rocks become of an abnormal type, possessing in a strange degree a mixture of granitic and gabbro characters. So peculiar is this feature of Delaware petrography that it seems best, for want of a better term, to designate these extreme types as *gabbro-granites*. We find all stages of transition from the typical form of this rock to those with but a trace of biotite, and in the other direction to those which are nearly true granites.

The biotite occurs generally as oblong blades, showing the usual basal cleavage and extinction of light parallel to the longest development; also as scales parallel to OP. All prismatic sections show strong pleochroism, i. e., a light yellow color and weak absorption for rays vibrating perpendicular to the cleavage or parallel to a, and a deep brown with powerful absorption for rays parallel to the direction of cleavage. Sections parallel to OP give, as usual, but little variation of color or absorption.

The biotite frequently contains as inclusions apatite crystals and grains of magnetite; otherwise poor. Magnetite also generally in

intimate association or contact with biotite, but never in borders around the latter. The biotite commonly shows those mechanical deformations so characteristic, i. e., a bending and twisting of the lamellæ. The relation of the biotite to the other minerals shows that it must have consolidated before the other magnesian silicates, but subsequent to the consolidation of the feldspar.

The plagioclase from several measurements on sections parallel to OP corresponds probably to labradorite, with it, and possibly replacing it in some cases. The less basic oligoclase can be proven to exist, as shown by examination of a number of cleavage fragments extracted from the coarser hand specimens. The feldspars in all cases contain the same characteristic inclusions already described. The highly micaceous rocks of Bellevue, which offer notably distinct characters, contain a greasy gray, coarsely crystallized feldspar. A cleavage leaflet of this mineral parallel to $M (\infty P \infty)$, as judged from the absence of twinning, gave with reference to the cleavage an extinction angle of -15° , and with concentrated polarized light the side appearance of an optic axis on the margin of the field. This would indicate a more acid labradorite in accord with the very acid character of these rocks. Quartz occurs in large amount in all the rocks of this class, several forms being largely a mixture of plagioclase and quartz, with little pyroxene or biotite; it is rich in liquid inclusions, with quiescent or feebly moving bubbles, which remain permanent at a temperature above 100°C . Most of the highly quartzose rocks of this class show the results of mechanical movements in a partial or an entire crushing of the more brittle quartz granules, protruding angles being commonly broken off, or again an entire side reduced to a mass of granules from the pressure exerted by surrounding larger individuals. Again, smaller fragile granules of feldspar wedged between large, tough, quartz masses have been partly or completely crushed. The rocks of this class cover all that region east of the Brandywine, and are found in such intimate association with the true gabbros as to render all attempts to accurately define their distribution quite ineffectual. As a rule, the gabbro-granites are massive, but assume a semi-foliated character whenever the biotite becomes an important constituent. In order to trace out the gradual passage from normal gabbro to those rocks of a highly granitic type it will be well to describe a few slides best illustrative of this point.

SERIES ILLUSTRATING TRANSFORMATIONS.

Characteristic Rock of the Brandywine Quarries.—Rock bluish black to gray, entirely massive. It consists primarily of a mixture of quartz and plagioclase, the former in large grains several millimeters in diameter, the latter in smaller particles. Bisilicates consist of hypersthene and diallage nearly equally represented, with biotite in small amount. Magnetite; apatite; the feldspar rich in inclusions.

Walnut Hill, Brandywine Hundred.—Rock bluish black, massive, much like the preceding, but contains a larger portion of bisilicates, which is mostly hypersthene

race of diallage; biotite in small amount. Quartz rich in liquid inclusions, apatite.

Turnpike, two and one-fourth miles from Wilmington.—Rock dark-gray, a peculiar acid type, consisting essentially of a mixture of plagioclase with scarcely more than a trace of biotite and pyroxene. Magnetite in small amounts.

Church, Concord Turnpike, North of Talleyville.—Rock black, semi-foliated consists mostly of plagioclase with much quartz; hypersthene and diallage biotite; magnetite.

ok Station, Wilmington and Northern Railroad.—Rock may be taken as an example of this class, presenting an equal combination of granitic and gabbro. Plagioclase is the principal constituent, with which is a smaller amount of diallage and biotite about equally represented. Quartz in a number of grains; brown hornblende in small amount; magnetite, apatite.

Concord Turnpike.—Rock much like preceding, except that it contains more pyroxenic matter than biotite. Quartz rich in inclusions of apatite and magnetite.

Del.—A black, thinly bedded, schistose rock, presenting a strong contrast with the gabbro-granites with which it is associated; it contains a much larger amount of biotite and pyroxene to feldspar than any of the other rocks of this class. On a superficial examination in the field it might be mistaken for an amphibolite, but under the microscope it is not to be separated from the highly massive gabbro-granites already described, except in the relative proportion between plagioclase and the other constituents. The rock is of special interest in showing the influence of pressure in causing a schistose structure in highly basic rocks, and its effect upon the highly acidic rocks with which it is associated. It consists mainly of a mixture of hypersthene and biotite, and a somewhat less amount of plagioclase. Magnetite abundant; apatite, the feldspars unusually rich in liquid inclusions.

Texture, as in many others, the rocky faces of a light, coarse-grained trap rock, marked and beclouded by lenticular and most irregularly shaped segregations of a darker fine-grained rock. These are found to be due to local variations in the proportion between feldspar and the iron-bearing silicates. This section, however, is practically identical with the latter, but while the preceding rock is a fine-grained area, the present type occurs as included masses whose dimensions are a few inches; the cases, however, are parallel and show the great tendency of variation within very limited areas. The rock consists mainly of a mixture of hypersthene and biotite, with a somewhat less amount of plagioclase; diallage in small amount; magnetite. Long, characteristic needles of zoisite richly developed; feldspars; apatite in stout prisms; acicular inclusions abundant.

Granitic Rock of the Bellevue Quarries.—A coarsely crystalline rock of a bluish gray color, which in hand specimens appears to be a granite, consisting of a mixture of greasy, gray labradorite, bluish quartz and biotite. It is usually quite massive, but shows in places in the large quarry walls an imperfect foliation. Under the microscope plagioclase and quartz predominate; biotite in subordinate amount; pyroxene, scarcely more than a trace. Magnetite and apatite rare. The quartz inclusions; these consist of darkly bordered cavities without bubbles, early and in groups, with many reddish brown inclusions, probably of calcite or elongated with tapering ends, acicular or imperfectly hexagonal. The rock also contains numerous black hair-like needles, possibly rutile.

NORITE.

Norite is more variable than the exact shade of color which the rocks assume, dependent upon the relative proportion between the feldspar and the bisilicates; thus the light gray norites are found in a

stages of graduation into the bluish black gabbros, with which they are associated. As a rule the rock is highly quartzose, containing veins and lens-shaped masses of this substance developed within the body of the rock. In the field these are readily recognized by their light gray or dirty white colors, which, in extreme cases, stand in strong contrast to the dark gray or bluish black colors of their associated rocks.

A typical section under examination is composed mainly of a very fine-grained mixture of quartz and plagioclase, which, in hand specimens, appears quite homogeneous; in this ground-mass are porphyritically developed larger grains of hypersthene and magnetite, with generally a few shreds of biotite.

The rocks are invariably massive, although in one prominent case along the Brandywine, a true norite lies adjacent to a highly schistose hornblende gneiss, while the passage from one to the other through darker gabbros is so gradual as to be indistinguishable. That these norites have been subjected to great pressure at one time or another, is evidenced by the nearly complete crushing of the quartz granules and the associated plagioclase, no rocks exhibiting stronger evidence of mechanical action than these.

The norites are found in such intimate association with the darker gabbros that it is quite impossible to restrict their distribution. Along the Brandywine are frequent alternations of lighter and darker trap, while over the whole of Brandywine Hundred one meets with out-cropping boulders truly characteristic of the rocks of this class.

THE IRON HILL GABBROS AND GABBRO DIORITES.

In macroscopical and structural characters the hypersthene rocks and diorites of Iron, Chestnut and Red hills seem to be quite distinct from those already described. That this difference, however, is more apparent than real, is shown by microscopic studies, which lead us to regard those under consideration as but modified forms of the finer grained, more acid gabbros of Wilmington. The Iron Hill rocks are essentially coarse-grained mixtures of triclinic feldspar and hypersthene, with a greenish diallage in variable amounts. They seem to be nearly or entirely free from quartz, and, so far as studies have been carried, of the basaltic variety of hornblende, but they contain a large amount of a green, paramorphic hornblende which, by entirely replacing the pyroxene, causes the rock to run into true diorites, with which it is found in the most intimate association. In the field, the rock generally possesses a very characteristic purplish gray color, and is sometimes so coarse as to yield large paramorphic crystals of a grayish, fibrous mineral, several inches in length, which have the physical properties of fibrous hornblende, but the cleavage angle of hypersthene. Microscopic examination proves these secondary crystals to contain cores of hypersthene, with fibrous hornblende as borders around them. The process of alteration of hypersthene to green hornblende is by no means a uniform one, but the most common method is as follows: A *crystal*

lual of hypersthene becomes surrounded by a fringe of colorless probably tremolitic, which, on the outer border becomes bluish to green. These last highly colored needles sometimes show but pleochroism, again, distinct bluish to yellowish colors. Under the nicols the whole fringe shows the most brilliant aggregation, revealing fibres sometimes placed in radiating tufts, at times perpendicular to the periphery of the hypersthene nucleus while again, the white fibres of tremolite form a most confused element. Later stages in the process show the gradual encroachment of this fibrous tremolite upon the hypersthene until finally it attains entire possession of the latter; thus we have in many sections consisting of a mass of tremolitic fibres surrounded by borders or less deep of green hornblende needles.

The stage in the paramorphism consists in the gradual deepening of the border of green hornblende aggregates until, finally, it attains entire possession of the secondary tremolite. Furthermore, there is a marked tendency of the fringes or cores of hornblende aggregates to assume a more compact nature, either upon the outer border or by the appearance of irregular nuclei within the body of the fibrous hornblende individuals. Thus we find in the last stage, individuals of percompact green hornblende with only the remains of small nuclei in hornblende aggregates within the latter. So abundant and diverse are the various stages of paramorphism in the relatively few sections which have been prepared that no link in the chain needs to be supplied by the imagination, and everything points to the gradual transformation of one mineral into another. Fig. 2 shows an early



Section illustrating the alteration of hypersthene into tremolite and fibrous green hornblende.

in this process of paramorphism. In the large piece a core of red, highly pleochroic hypersthene lies buried in a white sub-

stance which, under crossed nicols, is shown to consist of a dense mass of tremolitic fibres, yielding brilliant polarization colors. The shaded portion surrounding the white tremolite is composed of dark green hornblende fibres, giving aggregate polarization and rather feeble pleochroism. The large amount of magnetite, shown in the figure by the black granules, is a common associate of the secondary hornblende, being undoubtedly a separation product from the highly ferruginous hypersthene. In the paramorphic process just described the alteration has been entirely an outward one, the original hypersthene retaining its fresh appearance within the envelope of secondary matter; in many cases again, the hypersthene assumes a peculiarly fibrous character, while still retaining the characteristic pleochroism and parallel extinction of ordinary hypersthene. Between crossed nicols it is seen that this appearance is due to the development along the cleavage fissures of brightly polarizing fibres, which stand out prominently in brilliant colors when the cleavage lines of the hypersthene coincide with the plane of vibration of the light, in which position the hypersthene is dark. The nature of these inwardly developing fibres is not so evident in the early stages as when the original hypersthene becomes nearly or entirely replaced by aggregates of parallel white fibres, which, by polarizing identically with those in the loosely aggregated fringes, are probably tremolitic. Furthermore, this change rarely stands alone, but is accompanied by the usual outward fringing, the confusedly placed fibres of the latter often penetrating the original hypersthene. Sometimes the cores of white tremolite, instead of being made up of aggregates of fine threads, become more compact, and are composed of coarser fibres or columns placed parallel, which give angles of extinction from nearly 0° up to 15° , and in converging polarized light show the appearance of one optic axis which lies parallel to the cleavage line.¹ Furthermore, it must be mentioned that the fringes of green hornblende aggregates which surround the tremolite and hypersthene cores do not always consist of confusedly placed needles, but very commonly the green hornblende possesses a finely fibrous character similar to uralite. This finely fibrous hornblende possesses rather distinct pleochroism, i. e., bluish green and yellow, and gives between crossed nicols rather brilliant aggregate polarization. Unfortunately, the term *uralite* has generally been used in a rather ambiguous sense to indicate a substance which possesses the external form of augite but the cleavage and the optical properties of green hornblende, yet showing in addition a few special characters that, in the particular cases from which the current descriptions have been framed, are clear and unmistakable; in others, not so. Thus it is difficult to use the term *uralite* with that confidence with which others have used it. Suffice it to say, however, that the green hornblende aggregates which stand

¹Rosenbusch; Mikroskopische Physiographie. Second edition. Vol. 1, 1885, p. 465.

between the original hypersthene and the final compact hornblende possess all the optical characters of green hornblende, and that the process is quite similar to that which is generally called *uralitization*.

The paramorphic process next to be described is one of particular interest, inasmuch as, in many respects, it is a novel one. In this case the hypersthene, instead of being changed into fine, loosely placed aggregates, passes into a more compact, green hornblende. The properties of this hornblende are generally distinct—its pleochroism is strong, with the usual blue, yellow and green colors characteristic of ordinary green hornblende. The customary cleavage is well developed, but there is an entire absence of that finely fibrous habit characteristic of uralite. The optical orientation is uniform, and altogether the mineral appears perfectly compact. It forms borders around the hypersthene *with the usual intervention of a layer of white tremolite*. These borders, which, with ordinary light, appear to continuously surround the pyroxene cores, are, between crossed nicols, sometimes found to be made up of differently orienting areas of a compact nature, or again, very commonly a uniform extinction of light takes place throughout the whole border.

Notwithstanding some misgivings as to the secondary nature of these hornblende borders, as opposed to the idea of parallel growths of two original substances, the evidence still remains strong, and is based upon the following considerations: First, the process is identical with the ordinary alteration into uralite even to the intervention of tremolite, these two processes showing intermediate stages where the same individual is in one portion partly surrounded by a compact border and in another altered into loosely placed aggregates. Second, there are found all stages in the transformation, from large individuals of hypersthene with narrow fringes, to those with but traces of cores within individuals of apparently compact green hornblende. Bearing further upon this alteration of hypersthene to apparently compact green hornblende, it is necessary to consider the alteration of a monoclinic pyroxene, which proceeds in a like manner. The mineral which has been identified as a monoclinic pyroxene occurs in irregular grains of a greenish gray color, with an eminent cleavage, and frequently possessing the finely striated appearance characteristic of diallage. It is entirely unpleochroic, and gives high angles of extinction approaching 45° . These individuals of diallage are generally surrounded by borders of compact green hornblende, whose relations to the pyroxene cores are such as to be quite convincing regarding their secondary nature.

The contact between the diallage and the green hornblende borders is generally quite irregular, tongues and shreds of green hornblende continuous from the latter commonly penetrating far into the original pyroxene, and in one case under observation passing entirely through the core to the other side. The line of contact between the original and the secondary minerals is in some cases quite clearly defined and sharp, in others a *line of separation* can scarcely be discovered with the

highest powers. Accompanying this outward change there is observed the development within the pyroxene of numerous elongated inclusions of green hornblende, arranged generally parallel to the cleavage lines, and so covering the faces of the diallage sections as to give to the latter a peculiarly streaked appearance, often to the nearly complete replacement of the pyroxene. The outlines of these inclusions are indistinguishable with low powers ($\times 75$), in most cases, and their forms are very irregular, which, together with their number, renders an accurate delineation difficult. We have already mentioned an extension of the outer green border in the form of narrow tongues into the pyroxene substance; in a similar way we often observe tongues or necks of green hornblende connecting the outer border with some of the more irregular of these inclusions which spread and branch throughout the central nucleus. In Fig. 3 we have a typical case of this alteration of pyroxene.



FIG. 3.—Section illustrating the alteration of diallage into compact green hornblende.

The central core of pyroxene (BBB) is of a greenish gray color with eminent cleavage, as shown in the figure. It is entirely devoid of pleochroism, and gives an extinction of 33° . The border of green hornblende which surrounds it is entirely compact, its pleochroism is strong, with bluish and yellow colors. Between crossed nicols the portion marked AAA extinguished light uniformly at the same instant, while the portion DD deviated from the first position of extinction but a few degrees. With the very sensitive quartz plate the whole border showed uniform polarization colors, and was in the strictest sense compact. Within the body of the pyroxene cores are seen the characteristic inclusions of green hornblende, which is undistinguishable from that on the outer margin; two of these are continuous with the border by clearly defined necks. The outlines of these inclusions are somewhat *indistinct* and not so clearly defined as the drawing must show; they

shade gradually into the lighter pyroxene substance and on their borders fail to extinguish the light, but in their centers extinguish uniformly with the border, strongly testifying to the crystallographic identity of the two. The case of the alteration of diallage to compact green hornblende, which has just been described and figured, may be taken as a type of many others as observed in a study of the Iron Hill gabbros and gabbro diorites. Exactly similar cases in the Baltimore area have been described by Dr. G. H. Williams,¹ who regards these hornblende fringes and intergrowths as secondary; and in the Black Forest, by J. H. Kloos,² who regards them as original. In the example before us a great mass of evidence, as I believe, goes to favor the derivative nature of this compact hornblende, not alone because of the favoring facts which a single typical case can furnish, but partly because the study of a long series of thin sections reveals all stages in the passage from diallage to green hornblende, and this, therefore, weakens to a large degree the assumption that all these cases can be explained by any theory which implies an original crystallization of both minerals.

A change like this, involving the diallage, being, as I believe, the result of a molecular rearrangement more favorable to the lower temperature, may take place within the body of a diallage particle as well as upon its surface, and hence we observe in the rocks under consideration these two processes going hand in hand to the complete replacement of the original substance. What has already been written regarding the alteration of diallage to compact green hornblende can be brought as a further evidence regarding the secondary nature of those hornblende borders which surround the hypersthene, as the two kinds of hornblende occur together and are identical. It must be observed, however, that the process of paramorphism in the two cases is distinct. There has as yet been found no substantial proof of the direct alteration of hypersthene to compact green hornblende without the intervention of a colorless tremolite zone, and there is furthermore, as was observed by Dr. G. H. Williams, an entire absence in the body of the hypersthene of those obscurely defined green hornblende inclusions which so characterize the diallage; on the other hand, the change is an outward one in all cases, and as the same writer has admirably demonstrated, the hornblende appears to be due to a reaction between the hypersthene and the accompanying feldspar, the basic plagioclase furnishing the lime necessary to this change.

Regarding the paramorphism of diallage, it must be mentioned that while the method just described seems to be the most general one, there is also an alteration into true uralite similar to that affecting the hypersthene in so many instances. This consists in the gradual replacement of diallage particles by aggregates of light fibres, either

¹ Bull. U. S. Geol. Survey, No. 24, 1886, p. 41.

² Neues Jahrbuch für Mineral., III Beilage-Band, pp. 24-34, 1885.

tremolite or actinolite, which in turn changes outwardly into a light green finely fibrous hornblende.

The feldspars of the Iron Hill gabbro-diorites are apparently somewhat more basic than those found in the more acid gabbros near Wilmington.

The feldspar in a typical sample of the rock was separated by Mr. Diller as follows: The iron magnesian silicates were first separated by means of the Thoulet solution having a specific gravity of 2.877. The separated feldspar was then put into a solution of 2.592 specific gravity, in which an orthoclase indicator was slowly raised to the surface. The feldspar, thus cleaned of any suspected orthoclase, proved from microscopic examination to contain much included matter; to remove this a solution of 2.749 specific gravity was used. It barely lifted the feldspar, allowing portions containing the inclusions to remain behind. The feldspar thus obtained has a specific gravity between 2.749 and 2.592, with most of it as heavy as 2.749.

An analysis of the feldspar, by Mr. Riggs, is given below.

	I.	II.
SiO ₂ = silica	44.09	44.87
Al ₂ O ₃ = alumina	35.41	35.66
Fe ₂ O ₃ = ferric oxide (FeO not det.)	.51	.....
MnO = manganese oxide	trace.	.....
CaO = lime	18.47	—18.61
MgO = magnesia	none.	.....
Na ₂ O = soda	.99	.86
K ₂ O = potash	.19	.....
Loss on ignition	.35	.....
	100.01	100.00

Column No. II gives the theoretical composition of a feldspar with the formula Ab₁An₁₂. The mineral is therefore an intermediate member of the anorthite series, and is considerably more basic than the analyses of the feldspars separated from the acid gabbros indicate. A cleavage section of an Iron Hill gabbro-diorite feldspar was detached; it gave an extinction angle with the cleavage of -35° and had a specific gravity of 2.745, both answering again to anorthite. The development of inclusions within the feldspars is a notable feature of these rocks; these dust particles often so cover the twinning lamellæ as to make them appear like a series of parallel black bands, separated by lines of light coincident with the twinning traces; again, short opaque needles occur in abundance, but there seems to be an absence of those brownish prisms so characteristic of other feldspars.

The hypersthene and the diallage show the same micro-structure already described, and frequently the former mineral contains a number of light brown inclusions arranged parallel to the vertical axis, similar to those which in other hypersthene are regarded as brookite.

DIORITE.

To draw a distinct line between this type and the foregoing upon morphological considerations is quite impossible; the distinction is more properly a structural one, standing as it does quite apart in macroscopical characters. The main mass of a series of elevations, of which Indian Hill is the most prominent, consists of a fine-grained, greenish-black rock, from which all traces of pyroxene have disappeared, the rock being a silicate consisting of amphibole, either the colorless tremolite or the fibrous green hornblende. As we should expect, the rock is an extreme form of the one already described, in which the hypersthene is nearly or entirely disappeared, and has been replaced by secondary tremolite and green hornblende. The less advanced stages of the rock show cores of tremolite fibres, giving between crossed nicols brilliant aggregate polarization, with these cores in turn surrounded by borders of greater or less thickness of green hornblende aggregates; other portions are entirely green, showing cores of green hornblende needles passing into the compact form. Fig. 4 represents an individual of

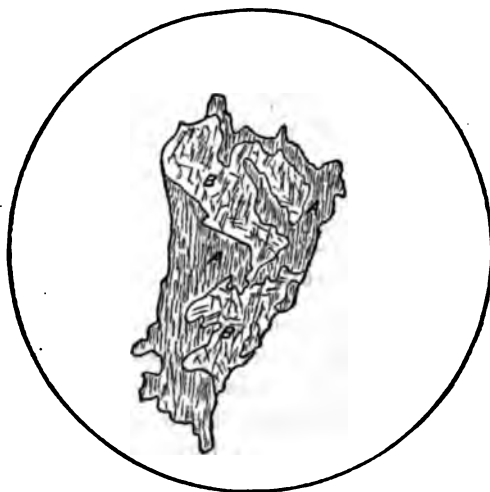


FIG. 4.—Section illustrating the alteration of fibrous into compact green hornblende.

hornblende which, with ordinary light, appears to be quite homogeneous; but with the use of the polarizer alone the whole is distinctly pleochroic, and more uniformly so over the portions marked AA. Between crossed nicols this last portion AA, including all the areas in the figure correspondingly shaded, extinguishes uniformly, and appears to be perfectly compact; the portions marked BB show brilliant aggregate polarization and appear to be composed of irregularly placed needles of green hornblende, which, from their marked pleochroism, are probably actinolite and not actinolite. The irregularity and indistinctness of the compact border, which a drawing can not well portray, leaves

no doubt whatever of its secondary nature, and furnishes a typical instance of that final transformation which is everywhere observed. The feldspars of the typical diorites of this order are particularly notable for the number of colorless inclusions which they contain. These show an arrangement commonly parallel to the twinning traces, and again in patches which greatly obscure the feldspar; they have a definite crystalline form, and polarize strongly and distinctly from the feldspar which encloses them; in size they average $.01\text{mm}$ by $.0075\text{mm}$, many, however, measured near $.005\text{mm}$ by $.0025\text{mm}$. The forms of these can be seen in Fig. 5. On account of their minuteness the extinction

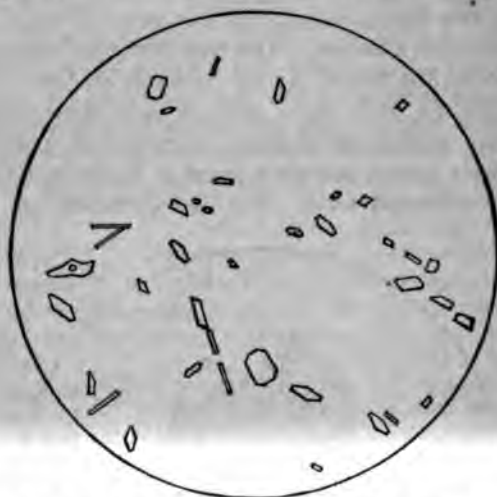


FIG. 5.—Inclusions within feldspar of Iron Hill gabbro.

could not be definitely determined, except that it was oblique to the prismatic edges. With these commonly occur numerous light green needles which, from their faint pleochroism, are probably actinolite. The feldspars of the highly paramorphosed diorites also show a notable alteration to epidote; the process, however, has seldom been carried beyond the formation of narrow fringes around ragged cores of plagioclase. In order, as before, to make still clearer the paramorphic tendencies already pointed out we will describe a series of sections.

SERIES ILLUSTRATING TRANSFORMATIONS.

Red Hill.—A coarse-grained purplish gray rock, consisting of a mixture of basic plagioclase, hypersthene, and diallage, showing an early stage in the transition to diorite. The hypersthene individuals, which are mostly large, and full of dark, acicular inclusions, are surrounded in the usual way by borders of tremolite and hornblende aggregates. In other cases individuals of hypersthene become surrounded by borders of perfectly compact green hornblende, with the usual intervention of a layer of white tremolite fibres. A light green diallage occurs in considerable amount, surrounded by the usual borders of compact hornblende, and full of obscurely defined green hornblende inclusions. Magnetite in large amount as a secondary product associated with the amphibole.

Road between Iron Hill and Sandy Bay.—Much unaltered hypersthene, and a light green pyroxene, with less plagioclase rich in inclusions. Both hypersthene and green pyroxene surrounded by borders of compact green hornblende with the usual characteristics. There is, however, an entire absence of anything like urallite. The hypersthene rich in inclusions; magnetite as usual.

J. W. Dyell's.—Somewhat further paramorphosed than the latter. All the hypersthene in this section is much altered. The hypersthene individuals show all stages of passage into aggregates of whitish parallel fibers, yielding the brilliant aggregate polarization characteristic of tremolite. This change seems to take place along the cleavage fissures, as well as outwardly. Individuals of hypersthene in this section are found in all stages of passage into these tremolitic aggregates; these cores in turn altering outwardly into green hornblende needles, or into a finely fibrous green hornblende, the feldspars rich in dust-like inclusions; magnetite in small amount much altered to oxide of iron.

West end of Chestnut Hill.—This section shows ragged remnants of hypersthene imbedded in aggregates of tremolite fibers which are outwardly green. Green pyroxene individuals surrounded by borders of compact green hornblende, and much streaked by inclusions of the latter; magnetite in large amount as dust particles within the bisilicates; the feldspars much clouded by inclusions and partly decomposed.

Iron Hill.—Shows a somewhat more advanced stage than the latter, with only traces of hypersthene embedded in the tremolitic fibers which outwardly become green. Inclusions in the feldspars abundant; magnetite.

Just below Iron Hill Station.—This rock shows no trace of hypersthene, but several pieces of a quite fresh light green diallage, which is found in all stages of replacement by aggregates of parallel fibers of light color, surrounded by borders of a finely fibrous, green hornblende, or by aggregates of green hornblende needles. The feldspars are notable for the dense clouds of colorless inclusions which obscure the twinning. The feldspars have their edges greatly corroded and fringed with epidote; magnetite with pyrite in small amount.

Iron Hill, road to Whitaker's.—A still further stage in the process. The pyroxene has entirely disappeared, and been replaced by aggregates of white tremolite fibers which outwardly are green. The feldspar much clouded.

GABBRO-DIORITE AND HORNBLLENDE GNEISS.

The normal gabbro is again found to merge by the addition of a green hornblende into the common hornblende rock of this region. The rock shows always a more or less perfect foliation, and has a black or greenish black color. Macroscopically it appears to consist entirely of hornblende, but thin sections show the presence of a considerable amount of basic plagioclase, also of either or both pyroxene elements; we have, therefore, adopted the term gabbro-diorite in this case, as in the others; where, however, the pyroxene becomes entirely replaced by green hornblende, the gabbro-diorites will merge into true hornblende gneisses. From massive gabbro to gneiss the same indistinct gradations are found, although in this case the structural change seems to more abrupt.

The hypersthene is identical with that in the normal gabbro; with it is associated a light green, nearly colorless, pyroxene, with the cleavage and other characters of diallage, occurring in large individuals several millimeters in diameter, of the same form as the green hornblende with which it is most intimately associated. It is the one pyroxene element

in this variety of gabbro-diorite, hypersthene being found in but small amount, rarely in more than a trace. The green hornblende which is such an important constituent of these rocks occurs in irregular grains and elongated individuals, showing the usual prismatic cleavage; its pleochroism is strong but distinct from that observed in the basaltic variety. Cross sections, in which the cleavage fissures intersect at about 124° and 56° , give for the a ray a light yellow, and for the b ray a green.

Sections which show an extinction parallel to the cleavage lines, and therefore sections parallel to the zone $OP : \infty P \infty$; give the color of the c ray, which is a bluish green; and with concentrated polarized light the appearance of one optic axis. A cleavage leaflet detached with a pen-knife and parallel to a prismatic face (∞P) gave, with reference to the other prismatic cleavage fissures, an extinction between 14° and 15° . The green hornblende shows no notable characters; it commonly is quite full of included grains of magnetite arranged parallel to the cleavage lines, and of black, opaque, acicular inclusions similar to those found in the basaltic variety. The feldspars of these rocks give somewhat higher angles of extinction than the true gabbros, and probably upon the whole indicate a more basic form. Numerous measurements were made where alternate sets of twinning bands extinguish at equal angles on each side of the twinning traces, and the angles were all high, indicating a highly basic feldspar.

Cleavage fragments parallel to (OP) were obtained from a typical Harmony Mill rock, and gave extinctions of -34° and -35° ; the specific gravity of the fragments was 2.745. Similar cleavage fragments from a typical gabbro-diorite below Jessup and Moore's, on the Brandywine, gave extinction angles from -34° to -39° and a specific gravity of 2.737. Thus, in common with the Iron Hill gabbro-diorite, those of this class seem to contain, at least in the more extreme types, the basic anorthite. It will be well to repeat here that the more basic character of the feldspars is in accord with the fact that the rocks of this type always contain in addition to hornblende the lime-bearing pyroxene (diplage), almost to the exclusion of the magnesian silicate (hypersthene), and with the further fact that these rocks are poor in quartz. Magnetite and apatite occur in these rocks, but never in large amount; they are also less quartzose, although quartz is frequently found in small amount. The intimate association of diplage and green hornblende at once suggests the question whether the latter should be considered a secondary or an original substance. The evidence of the direct passage of diplage into compact green hornblende, which was so near at hand in the Iron Hill gabbros, is not so clear in this type of rocks. The study of particular thin sections might lead one to explain the intimate association of pyroxene and green hornblende on the supposition of parallel growth, while others would incline the observer to the view that the hornblende might be a secondary product from diplage; hence

a most thorough comparison of many sections is the only safe ground for any conclusion. I am not therefore ready as yet to take any positive ground until further material shall have been collected and studied. It will be well, however, to weigh the evidence at hand and endeavor to explain the question in the light of all the facts.

In an examination of these rocks, after a study of the green hornblende gabbros, one is struck with the entire absence of continuous borders of green hornblende around the pyroxene. Inclusions of green hornblende within pyroxene, similar to those in the Iron Hill gabbro-diorites, are, however, common. These are, as a rule, very irregular in shape and so obscurely defined that even to high powers no well defined limit can be discovered. Their pleochroism is distinct, whereby they are placed in strong contrast to the inclosing unpleochroic diallage. At other times these included hornblende particles have such clearly-out boundaries as to leave little doubt of their primary origin.

Similar instances of the intergrowth of hornblende with diallage have been described at various times by Kloos, Streng, Macpherson, and Rohrbach, who have differently regarded these intergrowths either as original or as secondary. The analytical results of Rohrbach¹ testify to a marked difference in composition after separation between the pyroxene and the hornblende, and he is led to believe in the original character of both substances. The studies of Williams² give somewhat different results, and render possible the existence of hornblende practically identical in composition with diallage.

It was my intention to make a similar chemical study upon some very promising material, but the press of work in the laboratory of the U. S. Geological Survey at Washington has hindered the forthcoming results. The true nature of the green hornblende intergrowths as seen so commonly in this variety of gabbro-diorite can only at best be conjectured. Those of a more obscure outline are linked in the closest manner, as seen by a comparative study of sections, with those so common to the Iron Hill rocks, and appear to form such an indissoluble part of the diallage substance as to scarcely be regarded as original crystallizations.

I have spoken of the absence of continuous borders around individuals of pyroxene; an outward alteration is, however, none the less apparent. In some cases a clearly defined isolated individual of diallage has one end replaced by compact, green hornblende. I was at first inclined to pass over these instances superficially, but as attention was more closely drawn to them the conviction became stronger that these were cases of alteration of pyroxene to hornblende. In a notable case in view an individual about 1^{mm} by 5^{mm} is shown as a clearly de-

¹Ueber die Eruptivgesteine im Gebiete der Schlesisch-mährischen Kriedeformation: Tschermak's Mineralogische und Petrographische Mittheilungen, n. s., vol. 7, 1886, p. 24.

²Bull. U. S. Geol. Survey, No. 28, 1886, p. 44.

finer grain, which, crystallographically, can not be regarded as other than a unit. One end of this particle gives the color, pleochroism, etc., of the ordinary green hornblende, this hornblende substance extending also as a narrow, obscure border partly around the grain; the other end is of a lighter green color, totally unpleochroic, gives with reference to the cleavage a high angle of extinction, and is identical with the common green pyroxene of the section.

With a low power the two optically different portions shade indistinctly into each other; with the highest power no line of separation can be discovered. Between crossed nicols the green hornblende half gives uniform extinction where the color is deepest; where the two parts shade into each other and over the slightly pleochroic border of the diallage, no extinction occurs in any position; but at a point where the direction of vibration of the light makes a large angle about 38° with the cleavage, the inner portion of the diallage half of the individual extinguishes the ray and reveals two irregular nuclei of unaltered pyroxene, which surround a light green, faintly pleochroic substance.

Sometimes individuals which with ordinary light have the appearance of the common diallage show with the polarizer a faint pleochroism on the outer border. Between crossed nicols the compact center extinguishes uniformly, but the outer faintly pleochroic portion fails in any position to extinguish the light. Thus it seems that the pyroxene outwardly changes first into an optically obscure substance, which, consisting of a mixture of hornblende and diallage matter, gives no definite optical orientation. Furthermore, when the diallage appears outwardly to be replaced by compact green hornblende, it is generally separated from the uniformly orienting diallage by an intermediate zone of this last substance.

The perfectly fresh, compact nature of all the green hornblende is the strongest proof in favor of its original nature; the boundary lines of the individual grains are clear and well defined, and have not that ragged form so characteristic of secondary minerals. This, however, is in conformity with the facts favoring a theory of paramorphism. In all those cases where individuals of diallage show the hornblende pleochroism at one end or upon the border, the original boundaries of the diallage remain intact. This may be true of all paramorphic changes, which, as we understand, are merely molecular rearrangements, and imply none of those disintegrating influences which characterize pseudomorphic alterations, as in the case of the alteration of the hypersthene to green hornblende, where such a change requires a reaction between the original pyroxene and its adjacent lime-bearing feldspar.

Epidote.—A most important accessory of this variety of gabbro-diorite is the mineral epidote, which in certain instances occurs in such an amount as nearly to replace the feldspar. It occurs as colorless indi-

viduals, generally elongated columnar, also granular, which have a high index of refraction, as shown by their darkly marked relief. As would be expected from the absence of color in the thin section, the mineral is entirely unpleochroic. The elongated prisms, as is usual with epidote, extinguish the ray parallel to the longest development. The cleavage is most eminent in the direction of the base (0 P), also parallel to the orthodiagonal ($\propto P \propto$). One section showed two directions of cleavage, crossing each other at an angle of 115° , over which the light is extinguished for rays vibrating nearly parallel to the vertical cleavage, and at an angle of 25° with reference to the basal cleavage lines.

Such a section as this can only be one of epidote nearly parallel to the clinopinacoid ($\propto P \propto$).

As in the case of the Baltimore rocks the epidote is secondary from feldspar, the microscopic peculiarities being the same as figured and described by Dr. G. H. Williams. Granular individuals of epidote occur, in which cores of striated feldspar are found, whose outlines are so irregular and ragged as to leave little doubt as to their relations to the surrounding epidote. The secondary nature of the epidote is still further evidenced by the continuity of the cleavage lines of the feldspar across the epidote borders both above and below, and the extension of many of the twinning lamellæ with their marked interference colors for a certain distance beyond the limit of the feldspar cores, as determined with ordinary light. As shown by Williams, this alteration of feldspar to epidote is most frequent along the contact between a feldspar and a hornblende individual, the result of which is the corroding of both substances. A few slides show scarcely a grain of hornblende in its originally fresh condition, all the borders being highly etched and corroded into ragged forms, adjacent to which is invariably found the secondary epidote. This at once suggests the idea already advanced by Williams, that the epidote is due to a reaction between the feldspar and the hornblende, in which the hornblende took a far subordinate part, but a sufficient part to cause a considerable etching at points adjacent to the feldspar.

The gabbro-diorites and hornblende gneisses (F, p. 8) occupy a narrow belt which can be only roughly defined. Over the narrow tongue of rock which crosses the Brandywine at Jessup and Moore's, colored dark on the map, we have black schistose rocks, which to the eye appear to consist entirely of green hornblende, but under the microscope show a large amount of both hypersthene and diallage. Some hand specimens have a ground mass of hornblende and plagioclase, in which are porphyritically developed large bronze-colored crystals of hypersthene, and a light green foliated pyroxene. Farther to the west the same rocks outcrop back of the old almshouse in Wilmington. A section of this rock is typical of the class, i. e., thinly bedded schistose, with a slightly less amount of diallage than of green hornblende, and but a trace of hypersthene. Thence, in a direction due west, the rock occurs

abundantly in the Wilmington and Northern Railroad cuttings. Again, on both the eastern and the western sides of Harmony Mills a diallage-green hornblende rock is abundantly exposed; this rock contains a variable amount of epidote which give the same a characteristic greenish color. Farther west again, at White Clay Creek church, exposures of this same rock occur, but with less pyroxene in proportion to hornblende. From here to Newark and beyond the continuity of the rock is apparent, although the pyroxene seems to be entirely replaced by green hornblende, and the gabbro-diorite becomes a true hornblende gneiss. Between Harmony Mills and Iron Hill the outcrops are all of a greenish massive rock, in which there is much secondary epidote.

STRUCTURAL RELATIONS.

THE GABBRO BELT.

As will be seen from the map (Pl. I) the great rock mass which forms the subject of the present study is club-shaped in general outline, widest in its northeastern part and gradually tapering to the southwest. It forms an orographic part of the "syenitic areas" of southeastern Pennsylvania, already described as regards their structural habits by Mr. C. E. Hall.¹ It also continues with more or less breaks into Maryland, and is largely similar to the gabbro in the neighborhood of Baltimore, described by Dr. G. H. Williams. It will be seen that to the west of Newark the gabbro belt tapers quite rapidly and loses itself between the mica-schists; this, however, is the only point where the micaceous rocks are found upon both the north and the south sides of the gabbro mass. On the other hand, for the main distance, the plastic clays, of possible Jurassic age, rest upon the southern flank of the gabbro, with the mica-schists either overlying or dipping below these rocks on the north. The topographical position of the rocks of this belt, especially westwardly, is such as in many cases to obscure their natural boundaries. Skirting the slope of the upland region of the State, which lies north of the horizontal Mesozoic clays, is a terrace of Quaternary gravel, already described by me,² which rises two hundred feet or more above tide, and from which the gravel spreads southward as a uniform sheet twenty-five feet in depth. This gravel deposit, covering as it does all older formations, offers at points but a limited opportunity for the exposure of the rocks of this belt, consequently in a few places the line can not be accurately drawn. The northern limit of this area from its western point to Newark can be clearly traced, the gravels passing below these rocks. From Newark the line is traced close to White Clay Creek, by frequent outcrops, to Roseville and Harmony Mills, on the Philadelphia and Baltimore Railroad, where a fine exposure of an epidotic diorite occurs

¹ Second Geol. Survey Pa., reports C 4 on Chester County, 1883, and C 5 on Delaware County, 1885.

² *Am. Jour. Sci.*, 3d series, vol. 27, 1884, p. 189; vol. 29, p. 36.

the railroad cut. From this point the gravels so cover the older formations that for a mile or more no outcrops occur until Milltown is reached, below which there is found a hornblende rock of this formation. From Milltown occasional outcrops of a greenish gabbro occur along the upper Wilmington road until at Green Bank and Kilmensie stations frequent exposures of gabbro-diorite are found as minor interstratifications between mica-schists. Green and brown hornblende rocks, all containing both of the pyroxene elements, are found again a short distance from the last place, with an abrupt turn of the line to the north, upon the Lancaster pike, near the "Oak Hill" school-house. Then again the contact between schists and gabbro is well exposed just below Greenville station, on the Wilmington and Northern Railroad; thence the line turns abruptly north, the contact again occurring at Dupont station, on the same road; from here the line keeps close to the road from Dupont's to Rockland; then it passes abruptly northeastwardly, crossing the Concord pike near William T. Talley's place, above the Episcopal chapel, running into Pennsylvania, joining the gabbros of Delaware County, as delineated by Mr. C. E. Hall in his map of Delaware County. The southern boundary of the gabbro belt is made still more indefinite by the covering of gravel. From the western end to Harmony Mills the outcrops are confined to a narrow belt scarcely more than a quarter of a mile wide. From Harmony Mills a neck of gabbro, outlined by the outcrop of occasional bowlders of a green massive diorite-hornblende rock, runs nearly due southwest, connecting this last place with the Iron Hill mass. The northern boundary of this rather obscure neck cuts the main road from Newark to the hill near J. W. Evans's place, whence it runs west by northwest along Christiana Creek to the Philadelphia, Wilmington and Baltimore Railroad; thence it curves slightly to the southwest, keeping close to the railroad, crossing the railroad below Iron Hill station. Here it bends again to the south, or close to the railroad, to a point just north of Elkton, where it curves around Red Hill, returning again about one-half mile south of the old Philadelphia, Wilmington and Baltimore turnpike, gradually approaching nearer this road along the south slope of Iron Hill and Sandy Bray, to Ooche's Bridge, where the line again becomes the indefinite south line of the neck referred to. From Harmony Mills to beyond the Red Clay Creek the southern limit of the belt is mainly outlined by tracing out the northern boundary of the Mesozoic clays, which appear in the railroad cut back of Stanton and again at Newport. Between Newport and the Wilmington and Northern Railroad gabbro-diorites appear north of the turnpike and beyond the railroad to the south of the turnpike, where they run into Wilmington, crossing the center of the city, appearing most conspicuously at the Brandywine Bridge. From this point the line curves rapidly to the southeast, cutting the Delaware River near Edgemoor station. The thick mantles of Mesozoic and Quaternary deposits probably deeply bury a portion of this gabbro mass, offering

no opportunity to study its structural relationship on the south with other rocks possibly contemporaneous. That the gabbro is bounded on the south by the same mica-schists which occur to the north can only be inferred from analogy. We know that to the west of Newark the schists do occur both north and south of the gabbro belt, this exposure being due to the fact that beyond Newark the northern limit of the Mesozoic bends abruptly to the south, bringing the micaceous rocks nearer the surface. Furthermore it must be noticed that a number of lenticular bodies of gabbro-diorite have been found along the northern border of the main belt as included masses, rather than independent formations, and thus there is reason to believe that the main gabbro body bears a similar relationship to the great formation of micaceous rocks.

STRATIGRAPHY.

We have learned from a study of the various rock species and varieties that they may be divided into two classes from a structural point of view—the massive gabbros and the more or less schistose gabbro-diorites and hornblende gneisses. The portion more deeply colored upon the map is covered by a rock generally highly schistose, and containing a large amount of hornblende with a subordinate quantity of pyroxene, while the lighter portion is covered by the various varieties of massive gabbros, norites, and gabbro-granites. The boundary line between the two is of necessity general and somewhat arbitrary, since these two areas shade into each other quite indistinctly.

In this connection it must be understood that when one portion is spoken of as covered by schistose and the other as covered by massive rocks, reference is had only to their dominant features; in truth, we often find over the former area rocks perfectly massive including true gabbros, and in the latter area the local development of more or less schistose hornblende rocks. To demonstrate that the rocks of these structurally distinct regions are genetically one has been the aim of former petrographical work, while, at the same time, these results are confirmed in the field by a study of the contact between the rocks of the two areas at the excellent Brandywine exposures, where there is revealed a most gradual passage of massive gabbro into black schistose gabbro-diorite, instead of a stratigraphical break as might be looked for. So true is this, that it is impossible to define where one begins and the other ends. Therefore, as has been repeatedly urged, we can not regard the foliated hornblende rocks as metamorphosed sediments and the massive gabbro as a body of intruded "trap" of later origin, but that the whole formation belongs to an important class of altered eruptive rocks, so prominently brought to our notice of late, is far more probable.

In the region covered by the hornblende rocks both strike and dip *can be made out* with considerable accuracy. The latter, from the *extreme western point* of the belt to one near Milltown, is to the south-

at high angles. From Milltown onward the dip has been reversed to the northwest, the mica-schists in this case overlying the hornblende rocks and massive gabbros. The strike varies, but is generally within the limits of N. 40° to N. 60° E. In Delaware there is apparent conformity between the hornblende rocks and the mica-schists to the north. At Newark the hornblende gneiss dips with regular bedding to the south, the mica-schists pitching conformably beneath them; the strike for both is N. 55° to 60° E., dip 50° S. To the west of Newark the tongue of gneiss bears around slightly to the northwest, in conformity to which the inclosing mica schists have an average strike of N. 50° W. On both sides of the tongue the mica schists dip to the south, conformably inclosing the hornblende rocks. At Roseville the contact between the hornblende rock and the mica schist is not a distinct one as at Newark, but is marked by the occurrence of minor interstratifications of gneiss with schist. The same evident fusion of these two formations into each other occurs, as already pointed out, at Kiensie station and at Brandywine Springs. Along the Wilmington and Northern Railroad, between Dupont and Adams stations, near Henry Dupont's place, the mica-schists strike N. 50° E., dip 55° N., and are deeply exposed in the cut. A short distance farther south is another fine exposure of the black hornblende rocks, which strike N. 20° E., dip 40° N. Considering the great variability in the position of these rocks within very narrow limits, equally noticeable at this point, it is not at all probable that here any unconformity can be said to exist, notwithstanding that the actual contact of the two formations is not visible. Farther north, at Jessup & Moore's paper-mill, no evidence of unconformity can be discovered; on the other hand, the positions of the rocks of both formations are the same.

I have looked carefully for any other evidence of bedding except that coincident with the cleavage, but have found none. The so-called "bottoms"¹ in Delaware County, Pa., described by Mr. C. E. Hall, could not distinctly be made out in Delaware. Planes which might be taken for these were irregular and not continuous, and correspond more to joints than to planes of bedding. The unconformity discovered by Mr. Hall in Delaware County between the "trappean" rocks and the mica schists was not the same chronological bearing, should we regard the gabbros and their associated hornblende rocks as intruded masses. Possibly, again, these so-called "bottoms," as Mr. Hall has suggested,² may exist, but so obscurely defined as to be unrecognizable, in which event all that we have said regarding an apparent conformity must be changed, and our gabbros and gabbro-diorites must bear the same structural relation to the mica-schists that Mr. Hall claims they have in Pennsyl-

¹ These "bottoms" are bedding planes, which cut across the cleavage of the mica-schists, and consequently have a much lower angle of dip than that indicated by the cleavage.

² *Second Geological Survey, Pa.*, report 1835, Chap. 5, Part 1, p. 3.

vania, even to the borders of Delaware. But, however this may be, the real nature of the gabbros and their associated rocks, irrespective of chronological position, is not affected, and as no attempt is here made to determine the last point, the facts bearing upon it have no special relation to the aim of our investigation.

It must be noted, however, that if we consider the true planes of bedding of the mica schists to lie nearly horizontal, then the thin outlying lenticular masses of gabbro-diorite at Kiemensie and at Brandywine Springs, which are apparently interbedded with micaceous rock, must be regarded more strongly than ever as intruded bodies, cutting across the stratification. That these rocks are of this character the author is strongly inclined to believe.

The gabbros are devoid of all stratigraphical form, and it is only the development of local masses of hornblende gabbro, or the appearance of an obscure foliation in occasional cases that enables us to discern anything substantial. Everything learned from a study of the extensive quarries of bluestone along the Brandywine points to the conclusion that the rock before us is as truly eruptive as any ancient trap whose origin is indisputable. Huge jointage planes cut the rock into massive columns with rhombic cross-section. These continue downward at high angles indefinitely with persistent regularity, except when broken off by irregular cracks which, independent of the regular direction of the jointage planes, cut up the rock into massive pieces of various sizes and shapes. The jointage planes include two parallel sets—those running normal to the direction of pressure and nearly parallel to the axis of the mass, and those whose north ends bear a little to the left of lines perpendicular to the first set.

THE ORIGIN AND GENETIC RELATIONSHIP OF THE GABBROS AND THEIR ASSOCIATED HORNBLLENDE ROCKS.

Regarding the origin of the Delaware gabbros, two theories might be advanced—that which would regard them as highly metamorphosed sediments, and that which would consider them as metamorphosed eruptive rocks.

In considering the former view but little need be said. The opinion which has been advanced that the gabbros, variously called "syenites" and "diorites," were but the so-called metamorphic hornblende gneisses more highly metamorphosed, is, I believe, entirely irrelevant. Such a change as this would involve the alteration of hornblende into pyroxene, an idea which probably never would have been advanced had the real nature of these massive rocks been understood. Pyroxene we are taught to regard as a product of direct igneous fusion, the hornblende arrangement of the molecules being more in accord with the conditions of ordinary metamorphic action; hence it is questionable whether, in any case, the more advanced stages of ordinary metamorphic action could ever result in the transformation of horn-

blende into pyroxene, or of a hornblende rock into a gabbro. On the other hand, we have had of late abundant and reliable instances where the alteration of pyroxene has occurred. The recent results on a large body of workers on both sides of the Atlantic, all go to explain the occurrence of schistose hornblende rocks in these instances by paramorphic or pseudomorphic changes affecting an original gabbro. Over the Delaware area the intimate association of pyroxene and hornblende rocks meets with an easy explanation from the facts set forth in previous pages, and the genetic unity of the two has been thoroughly revealed.

In the brown hornblende gabbro-diorites, which structurally possess all the characters of hornblende gneisses, we see this genetic unity admirably displayed in the gradual passage from massive to highly schistose forms, even a field study, without the use of a thin section, enabling us to trace forms which show all grades of semi-foliation, and which to the unaided eye show much hornblende in addition to pyroxene. In the Iron Hill gabbros we have seen the clear passage into dioritic forms through a two-fold alteration of hypersthene into uranalite, and of monoclinic pyroxene into hornblende of the compact variety. In the Wilmington and the Harmony Mill green hornblende rocks an absolute proof of the origin of the hornblende from the green pyroxene is, as we have seen, impossible at this date; their genetic unity with the gabbros, however, is none the less evident from an equally gradual transformation from massive to schistose forms.

While it would be unwarrantable to make any detailed statement as to the exact origin of the Delaware gabbros, it is at least evident that they were at one time in a more or less molten state. This is particularly evinced by the occurrence within the quartz and the feldspar of what appear to be gas pores and glassy particles, and from the caustic action which a few of the earliest-formed minerals have suffered under the influence of none other than a molten liquid.¹ Thus we believe ourselves warranted in the assumption that all the rocks included in the scope of this paper were at one time molten, whether we regard this original magma as one truly gabbro in its nature or strongly dioritic through the presence of original hornblende. Supposing, then, the matter entering into these schistose-hornblende rocks to have been at one time molten, i. e., a true dioritic magma, the structural habit which they show we must regard as the result of some external secondary influence. This influence many geologists in like cases of late have attributed to pressure. That a powerful pressure affected the whole gabbro body is shown in many instances. In thin sections of the schistose gabbro-diorites and hornblende gneisses, which lie transverse to the plane of foliation, the effect of pressure is seen in a flattening and an elongation of both pyroxene and hornblende individuals, producing a structure similar to the so-called "flaser structure" of the German

¹ See observations on apatite crystal, op. cit., p. 13.

petrographers. Thin sections cut in these directions show a definite arrangement of the bisilicates, which appear as elongated particles whose greater axes are commonly six times the length of the shorter, these greater axes lying parallel to the planes of foliation, and at right angles to the directions of pressure. Not only have these individuals been pressed into flattened and elongated forms, but in some cases they appear bent, as shown by the curved positions of the cleavage lines and disturbances in the optical symmetry of the substance.

Quartz, wherever it occurs, commonly shows fracture—a marginal crushing—and sometimes an entire destruction, while the smaller grains of feldspar wedged in between the rigid quartz granules show also the results of mechanical action in crushing phenomena. That the pressure which, as I believe, has resulted in the structural change above mentioned, must have affected the whole gabbro mass, is shown by the occurrence within perfectly massive rocks of those highly schistose. The schistose forms of our gabbro derivatives may be grouped under two heads: First, including those varieties of gabbro-granite which contain a considerable amount of mica; and second, nearly all those rocks which contain a notable amount of hornblende, original or secondary, the degree of foliation bearing a direct ratio to the amount of hornblende.

It is a familiar fact that many truly eruptive granites merge into granitoid gneisses and into true gneisses by an increase of mica, the result of a normal variation. Exactly the same thing is observed in the study of the gabbro-granites, these rocks showing all degrees of semi-foliation. At Bellevue the prevailing rock is a coarse gabbro-granite containing about an equal mixture of hypersthene and mica. This rock is upon the whole quite massive, but shows in the quarry walls a continual tendency towards semi-foliation through increase of biotite with probably accompanying pressure. With it is associated a jet-black rock thinly bedded and highly schistose, which to general appearance seems to have no relationship with the former. A thin section, however, shows that this rock owes its black color to a large development of hypersthene and biotite, and its schistose structure to the relatively larger amount of biotite as contrasted with the highly quartzose and feldspathic rocks which surround them. That these massive rocks have been subjected to great pressure is shown by mechanical deformations in a crushing of the quartz and in an occasional bending of the mica laminae. We must recognize, then, that the reason why the more highly micaceous rocks are more strongly foliated is not alone one of difference of composition, but because a given pressure was more capable of producing a structural change in rocks of this character than in the more quartzose and feldspathic forms associated with them.

The intimate association of schistose hornblende rock with massive gabbro is admirably revealed in the Brandywine section at Jessup &

ore's paper-mill. A reference to the map will show a tapering of the tongue of schistose hornblende rocks running out into a tongue as it crosses the Brandywine. In the railroad cut below the paper-mill is an exposure of highly schistose thinly bedded green hornblende gabbro-diorite (F, p. 8), which upon either side gradually shades into a grayish perfectly massive gabbro without the least sign of any distinct line of separation between the two structurally different rocks. That the two structurally distinct rocks are genetically one is conclusively shown by an examination of a number of thin sections of each. How, then, are we to account for a schistose mass wedged between perfect massive rocks? Not from an effective pressure in one case and its absence in another, but rather, as we can well see, because of the different effects which a given pressure will have upon rocks of different mineralogical characters. It is not that pressure has not affected highly feldspathic and quartzose norites, but that pressure in these cases has been ineffective in producing a structural change—such rocks as these showing a crushing rather than a flattening of the mineral constituents. It would be difficult to prove conclusively whether the pressure which has resulted in the foliation of these rocks acted previous or subsequent to the consolidation. Writing of the Lizard gabbros near Voose, near Landewednack,¹ J. J. H. Teall finds that in those places where the foliation is most eminently developed he sees exhibitions of profound earth movements; and such seems to be the view of Loss and Lehmann, who consider these changes the result of great orographic or mountain-making influences, such as have affected consolidated rocks of all formations. The reverse dip in the eastern and in the western parts of the gabbro area, together with the twisted and contorted condition of the more highly foliated rocks in places, is proof that they have suffered the effects of orographic forces since consolidation.

The relation between pressure or foliation and paramorphic changes is not what would be looked for. Those hornblende rocks which show the foliation habit eminently developed, i. e., those which cover the dark shaded area on the map, exclusive of the Iron Hill body, are the veins in which we find an original brown hornblende or a green hornblende whose secondary nature can not be definitely established. The Iron Hill gabbro-diorites, in which the derivative nature of the hornblende is alone clear, show invariably a massive character. Many thin sections before the writer are taken from rocks strongly foliated, but with the hypersthene and diallage which they contain perfectly fresh and the brown hornblende apparently original. Such facts as these indicate that pressure is not in all cases sufficient to produce paramorphic changes, even though this pressure be great enough to cause structural alteration; and again that paramorphism may be eminently revealed where we have no evidence of the action of these mountain-building forces.

¹The metamorphosis of the Lizard Gabbros, J. J. H. Teall, *Geol. Mag.*, Dec. 1, 1886, p. 488.



INDEX.

	Page.		Page.
Analyses of feldspar.....	12, 28	Hyperstene-gabbro	10-15
Apatite	14, 15	Iron Hill gabbros and gabbro-diorites	22-29
Areas of exposures of gabbro.....	36-38	Irving, R. D., acknowledgments to	7
Biotite	15, 19	cited	17
Cross, Whitman, acknowledgments to.....	7	Klooa, J. H., cited	27
Diallage	11	Lizard gabbros	43
Diller, J. S., analyses of feldspars by.....	12, 28	Magnetite	14
Diorite	29-31	Norite	21, 22
Epidote	34, 35	Origin and relationship of gabbros.....	40-43
Feldspar	11	Pressure, effect of.....	41-43
analyses	12, 28	Quartz	8, 9, 15, 42
Gabbro-diorite	15-19	Riggs, R. B., analyses of feldspars by	12, 28
and hornblende gneiss	31, 36	Rohrbach, cited	33
Gabbro-granite	19-21	Stratigraphy of Delaware rocks	38-40
Garnet	15	Table showing variations of gabbro.....	8
Hall, C. E.....	36-39	Teall, J. J. H., cited	43
Hawes, G. W., cited.....	17	Törnebohm, cited	8
Hornblende	9, 15	Williams, G. H., acknowledgments to	7
Hyperstene	10	cited	8, 17, 27, 33



DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

EOLOGICAL SURVEY

No. 60



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

REPORT OF WORK DONE

IN THE

DIVISION OF CHEMISTRY AND PHYSICS

MAINLY DURING THE

FISCAL YEAR 1887-'88

F. W. CLARKE, Chief Chemist



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



CONTENTS.

	Page.
ce.....	11
hemical structure of the natural silicates. By F. W. Clarke.....	13
nickel ores from Oregon. By F. W. Clarke.....	21
al soda: Its occurrence and utilization. By Thomas Mearns Chatard..	27
omposition	28
Sodium sulphate	29
Sodium chloride	30
Sodium carbonate.....	31
Sodium bicarbonate.....	34
Sodium sesquicarbonate.....	35
Localities and mode of occurrence.....	36
Hungary.....	36
Egypt	38
Armenia	39
Venezuela	40
North America.....	41
Wyoming.....	42
Ragtown Lakes, Nevada.....	46
Ragtown Soda Works.....	49
Mono Lake, California.....	53
Abert Lake, Oregon.....	53
Dry deposits.....	55
Owen's Lake, California.....	57
Owen's Lake Soda Works.....	58
Experiments on the evaporation and fractional crystallization of the water of Owen's Lake.....	59
Evaporation	59
Fractional crystallization	61
Discussion of results	65
Fractional crystallization of water of Mono Lake.....	65
Urao.....	67
Native urao from Venezuela	67
Native urao from Egypt.....	68
True character of Trona, or the native sesquicarbonate	69
Artificial production of sesquicarbonate.....	72
Urao from Owen's Lake	75
Artificial production of urao; experiments and discussion of re- sults.....	78
Analytical methods.....	85
Origin of natural soda	83

	Page
Natural soda—Continued.	
Cause of the red color of alkaline brines	95
Leaching of alkaline soils and clays	96
Conclusions	99
Analyses of six new meteorites. By J. E. Whitfield	103
The Rockwood meteorite	103
Chattooga County meteorite	106
Taney County meteorite	106
Linnville Mountain meteorite	107
Fayette County meteorite	107
San Bernardino County meteorite	114
Two sulphantimonites from Colorado. By L. G. Eakins	115
Coefficients of volatility for aqueous chlorhydric acid. By Robert B. Warder ..	119
Experimental method	120
Calculation of results	121
Discussion of results	122
Analyses of jade. By F. W. Clarke	123
Mineralogical notes:	
1. Petalite from Peru, Me. By F. W. Clarke	129
2. Spessartite from Amelia County, Va. By F. W. Clarke	129
3. Oligoclase from Bakersville, N. C. By F. W. Clarke	129
4. Willemite from Franklin, N. J. By F. W. Clarke	130
5. Descloizite from Beaverhead County, Mont. By W. F. Hillebrand	130
6. Preliminary remarks on North American uraninites. By W. F. Hillebrand ..	131
7. Dumortierite from New York and Arizona. By J. E. Whitfield	133
8. Xanthitane from North Carolina. By L. G. Eakins	135
9. Triplite from the Black Hills. By L. G. Eakins	135
10. Kaolin from Gunnison County, Colo. By L. G. Eakins	136
11. Native gold from Persia. By C. Catlett	137
12. Pyroxene and serpentine from Montville, N. J. By C. Catlett	137
The subsidence of fine solid particles in liquids. Second paper. By Carl Barus ..	139
A new method of making alloys. By William Hallock	147
Miscellaneous analyses:	
Rocks collected by R. D. Irving	149
Novaculite from Marquette, Mich.	151
Brick clay from New Ulm, Minn.	151
Rocks from Montana	152
Eruptive rock from the Henry Mountains, Utah	154
Rocks from New Mexico	155
Lavas from near Lassen Peak, California ..	155
Basalt from Mytilene	158
Inclusion in diorite from Cruger's Station, N. Y.	158
White earth from Talladega, Ala.	158
Sandstone from Berea, Ohio	158
Knox dolomite and residual clay, from Alabama	159
Dolomite from Tuckahoe, N. Y.	159
Dolomite marble from Cockeysville, Md.	159
Marble from Louisiana	160
Limestones from Ohio and Indiana	160
Coquina, coral, coral rocks, etc.	162
Iron and manganese ores	164
Coal and coke	169
Efflorescence from Cliff Creek, Colo	170

CONTENTS.

Miscellaneous analyses—Continued.

Salt from Hutchinson, Kans.....	I
Water from Lincoln County, N. C.....	
Water from St. Augustine, Fla.....	
Water from McLeansborough, Ill.....	
Water from Lebanon, Mo.....	
Water from Hominy Hill, Ark.....	
Water from near Denver, Colo.....	
Water from Matilija Hot Springs, California.....	



ILLUSTRATIONS.

	Page.
FIG. 1. Section showing association of genthite and quartz.....	24
2. Section showing association of genthite and serpentine.....	24
3. Section showing association of genthite and serpentine.....	24
4. Apparatus for determination of water.....	86
5. The Rockwood meteorite.....	103
6. Section of Rockwood meteorite.....	104
7. The Fayette County, Texas, meteorite.....	109
8. Vein in Fayette County meteorite.....	111
9. Portion of above vein highly magnified.....	113



PREFACE.

The present bulletin, like its predecessors numbered 9, 27, 42, and 55, contains the results of work completed in the Division of Chemistry and Physics during one fiscal year. Part of the investigations reported were begun in previous years; and other researches which are now under way are reserved for future publication. Still other work has appeared, or will appear, in separate bulletins; so that this issue represents only a part of the results obtained during the year which covers.

F. W. CLARKE,
Chief Chemist.



WORK DONE IN THE DIVISION OF CHEMISTRY AND PHYSICS IN 1887-'88.

THE CHEMICAL STRUCTURE OF THE NATURAL SILICATES.

BY F. W. CLARKE.

In any attempt to discuss the chemical structure of the inorganic silicates we are met at the outset by difficulties which are partly real and partly imaginary. On the one hand we have to deal entirely with non-volatile solids, of which, because of their fixedness, we can not certainly ascertain the true molecular weights. They are, furthermore, insoluble and, chemically speaking, non-plastic; that is, they yield but feebly to reagents, so that the changes of which they are structurally capable can rarely be studied in the laboratory. These difficulties are very real. On the other hand, most of the definite silicates are natural minerals, and as such are commonly supposed to have a bewildering complexity of constitution. This difficulty is only apparent, not real, and is due to several causes. First, few mineral species occur in state of even approximate chemical purity; and secondly, many of them, being isomorphous, crystallize together to form seemingly homogeneous bodies to which rational formulæ can hardly be assigned. Impurities, indefinite crystalline mixtures, and defective analyses account for many apparent complications. Eliminate from any group of natural silicates these disturbing conditions, and we shall find in every case a simplicity of composition far removed from the complexity which is popularly assumed. Even on theoretical grounds we should expect simplicity of structure. The mineral silicates are, as a rule, exceedingly stable compounds, while complex molecules are relatively unstable. They are formed in nature under conditions of high temperature, or are deposited from solutions in which many reactions are simultaneously possible; circumstances that are strongly adverse to the development of great complications of structure. Finally, they are quite limited in number, only a few hundred at most being known; whereas, if complexity were the rule among them, slight variations in origin would produce great variations in character and millions of different minerals.

would be generated. That few substitutions occur is presumptive evidence that only few are possible, and hence simplicity of constitution is to be inferred. In fact, we find the same small range of mineral species occurring under the same associations in thousands of widely separated localities, a few typical forms containing a few of the commonest metals being almost universally distributed. The longer the evidence is considered the more overwhelming the argument for simple silicate structures becomes.

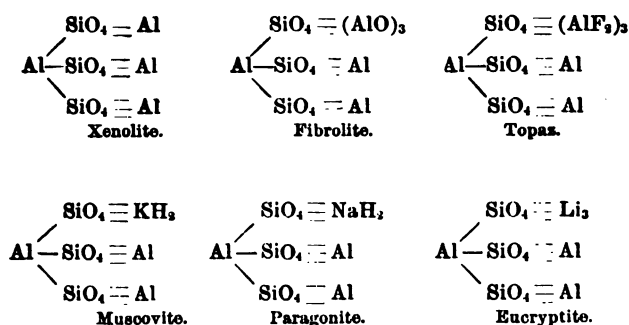
Suppose now that for any given silicate the empirical composition has been ascertained, how can its chemical structure be determined? We can not measure its vapor density and so deduce its molecular weight; but the problem is not therefore necessarily hopeless. Several lines of available evidence are open. In some cases the compound may be synthetically reproduced in the laboratory, a kind of mineralogical investigation in which rapid progress is now being made. Again, the constant association of the species with certain others sheds light upon its genesis, and still oftener its alterations in nature furnish important details. An alteration product, despised by the crystallographer, is really a record of chemical change, and such products may be of the highest scientific interest. In a few researches they have been produced artificially by reactions which were prolonged for months at a time, and so a mass of evidence is slowly accumulating, strictly analogous in kind to that which the organic chemist chiefly depends upon for ascertaining the structure of a hydrocarbon. All these lines of evidence are legitimate, and all converge towards truly scientific conclusions. We know that certain silicates originated together, and that each alters in certain definite ways; and from these facts we may draw perfectly fair inferences as to chemical structure and deduce rational formulæ which shall give fuller expression to our knowledge. The evidence for such formulæ is less perfect than that at the command of the carbon chemist, but it is none the less substantial so far as it goes. It is, furthermore, cumulative.

About three years ago, while I was working tentatively at the problem now under discussion, I received for examination certain specimens of topaz which were deeply altered upon their surfaces. Upon investigation the alteration product proved to be a variety of muscovite, and a study of the empirical formulæ of the two minerals revealed an unexpected relation between them. Further study brought out more extended relations connecting them with several other silicates, and by a natural series of steps I was led to adopt as a working hypothesis the supposition that double salts might be regarded as substitution derivatives of normal salts. This hypothesis, since then steadily applied to the discussion of the silicates, appears to be supported by a weighty mass of evidence, and it leads to the development of a series of structural formulæ which satisfy many conditions. They express and interpret known relations, lead to the detection of others, and point out suggestive and profitable

lines of research. By these tests any hypothesis must stand or fall, and one which, meeting them successfully, has at the same time philosophical significance, may be fairly looked upon as valid.

That the great majority of the natural silicates are double salts need hardly be stated, and that a very great number of them contain aluminum is also a commonplace of chemistry. Of the latter some are orthosilicates, and some are meta-compounds; and the problem is to show how each series may be derived from its corresponding normal salt. As the orthosilicates are the most important, we may begin with their consideration. They represent the maximum of complication and offer the greatest difficulties.

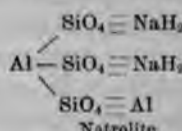
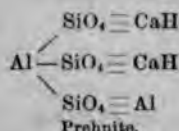
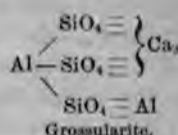
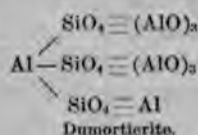
Fortunately, the orthosilicate of aluminum $\text{Al}_4(\text{SiO}_4)_3$, occurs in nature as the mineral xenolite. This species, which is now well established, was long thought to be an impure variety of fibrolite, Al_2SiO_5 ; and in their optical properties the two are apparently identical. Fibrolite bears the closest of relations to its isomer, andalusite; and to the latter, topaz, $\text{Al}_2\text{SiO}_4\text{F}_2$, is crystallographically akin. Topaz, as I have already stated, alters into muscovite, $\text{Al}_3\text{KH}_2(\text{SiO}_4)_3$; and so also does eucryptite, AlLiSiO_4 . To these compounds we may add paragonite, which is merely a sodium mica, and we have at least six silicates, including the normal salt, which are all evidently related to each other. That their empirical formulæ show little or no connection is due to the fact that they do not represent true molecular weights, and on this point our fundamental hypothesis gives us a key to the problem. If we triple the formulæ given for fibrolite, topaz, and eucryptite, the substitution theory which I have suggested at once becomes applicable, and the derivation of all the others from xenolite is easy. The following structures will make this conception clear:



In the second of these formulæ the univalent group $-\text{Al} = \text{O}$ is assumed, and in the third we have the corresponding group $-\text{Al} = \text{F}_2$. I think no chemist will regard these assumptions as strained.

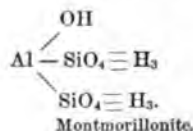
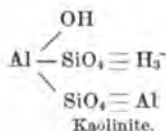
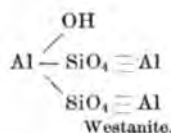
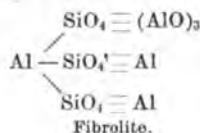
Now the foregoing symbols all represent a series of salts derived from the first one by various substitutions of a single aluminum atom.

But further replacements are theoretically possible, and the following minerals seem to illustrate them:



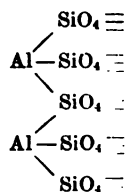
Dumortierite, which has been little studied, appears to be related to fibrolite, and the formulæ exhibit a relation. Grossularite, the lime alumina garnet, is a common associate of muscovite, a fact which lends verisimilitude to the formulæ given above. The other two formulæ represent the known composition of prehnite and natrolite, but whether they indicate any deeper relations is not yet proven. They do, however, suggest lines of investigation, and so far fulfill a useful purpose. If they are true, prehnite should be derivable from garnet, and garnet and muscovite ought to be mutually derivable from each other. That garnets do alter into micas is already well known, although the exact character of the change is undetermined, and the micas involved in the reaction appear to be more complex than muscovite.

Returning now to fibrolite, we find that it is a mineral which is liable to alter through a process of hydration. Some of its alteration products have been described as species, notably under the names *wörthite* and *westanite*, the latter being apparently the final product. Certain other species of the same group frequently undergo a sort of degradation into clays, which, unfortunately, are often too impure to admit of precise formulation. Still, of the several clays which are certainly definite, two seem to fall into series with fibrolite and westanite, as the following structures show:

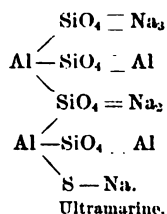
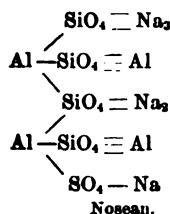
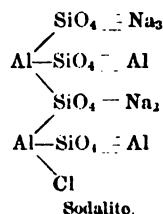
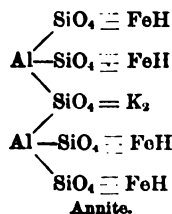


Now, suggestive as these formulæ are, they represent only a selection out of a much larger number, all of which seem to follow essentially

same structural rule. If the case rested here it would still be a strong one, but it becomes even stronger when we study some of the more complex orthosilicates, and some of the silicates containing other organic acids. In most of the foregoing instances we have one minimum atom linked with three of the orthosilicic groups, making part of fundamental nucleus to which the other atoms of each molecule are attached. But in many cases we seem to have a semipolymerization of that nucleus which results in the elimination of one of the silicas, leaving a new group of atoms which may be represented as follows:



This group, saturated by various bases, seems to exist in many natural silicates, notably among the iron and magnesian micas; and from it certain mixed salts, like sodalite and nosean, may be represented as derived. Thus, to cite a few examples, we may write:

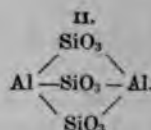
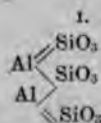


The last of these four formulæ is purely hypothetical and rests upon the recognized mineralogical analogies between lapis lazuli and nosean. It is, however, a formula which should be capable of synthetic verification, for ultramarine, itself a product of synthesis, yields many derivatives, the formation of which can be systematically studied. Possibly the lines of research followed by Lemberg, in his work on the alterations of elacolite, may be fitly applied to the investigation of lapis lazuli. As for annite, I have discussed its relations, together with those of the lithia micas, in a previous paper,¹ in which I have also given some

¹ Amer. Journ. Sci., Nov., 1886.

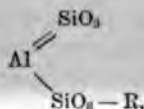
suggestions concerning the part played by fluorine in lepidolite, cryophyllite, and phlogopite.* Sodalite and nosean were considered in a still earlier paper,¹ in connection with cancrinite, nephelite, and other species. It is hardly necessary to repeat either discussion here.

Passing now to the metasilicates, we find ourselves, as regards the aluminous salts, at some disadvantage. The normal compound, $\text{Al}_2(\text{SiO}_3)_2$, is not known to exist by itself in nature, although certain of its derivatives are common. Its formula, however, may be written in two ways, as follows, and to one of these types some of the double aluminous metasilicates should conform:

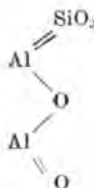


Which of the two is best sustained by evidence?

To answer this question we may appeal to several well-known minerals, such as spodumene $\text{AlLi}(\text{SiO}_3)_2$, jadeite, $\text{AlNa}(\text{SiO}_3)_2$, leucite, $\text{AlK}(\text{SiO}_3)_2$, and pyrophyllite, $\text{AlH}(\text{SiO}_3)_2$. All of these can be generalized under one formula, thus:



which is directly derivable from normal salt No. 1, and is not derivable from No. 2. Furthermore, kyanite, an isomer of fibrolite, Al_2SiO_5 , is regarded by Groth and others as a basic metasilicate, for reasons which need not be reconsidered here. As such its formula is $\text{Al}_2(\text{SiO}_3)\text{O}_2$, which may be derived from either of the formulæ for the normal compound. But pyrophyllite often occurs as the gangue of kyanite, which suggests a genetic relation between the two, and so makes it highly probable that the latter mineral should be written



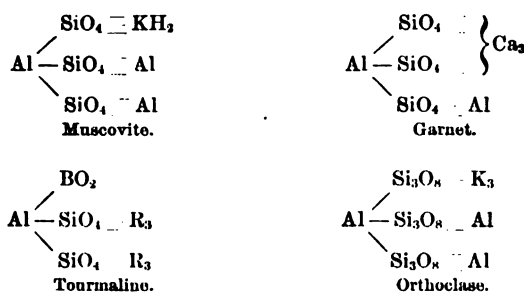
rather than as a derivative of the second formula for $\text{Al}_2(\text{SiO}_3)_2$. Formula No. 1, then, is the more probable formula for aluminium metasilicate. Two isomers may be possible, but the evidence so far favors only one compound.

¹Amer. Journ. Sci., April, 1886

In addition to orthosilicic and metasilicic acids, at least two other silicic acids correspond to known salts. These are the compounds $H_2Si_2O_5$ and $H_4Si_3O_8$. Still more are possible, but it is not necessary to assume them in order to account for known minerals. Derived from $H_2Si_2O_5$ we have a few species, notably petalite, $AlLi(Si_2O_5)_2$, which is the equivalent of spodumene in structure. The other acid, $H_4Si_3O_8$, is represented only by the species albite and orthoclase, $AlNaSi_3O_8$ and $AlKSi_3O_8$ respectively. If we triple these formulæ we have structures quite analogous to the orthosilicates, in which the normal aluminum salt $Al_4(Si_3O_8)_3$ is the starting point for derivation. Now it is almost universally believed, in accordance with the views of Sterry Hunt and Tschermak, that the triclinic feldspars consist of various mixtures between albite and anorthite as two extremes. If our fundamental hypothesis is true, each of these minerals is derived by substitution from a normal salt, and the formulæ so deduced become strikingly suggestive:



Anorthite is the lime salt corresponding to the first formula, and albite is the soda salt corresponding to the second. Another comparison is even more striking. The four silicates most frequently associated with each other in granite veins are muscovite, garnet, albite or orthoclase, and tourmaline. Tourmaline, according to the analyses made by Mr. Riggs in the laboratory of the United States Geological Survey, is always represented by the general formula $R'_3BO_2(SiO_4)_2$, in which at least the equivalent of R'_3 is present as aluminum. This gives us the following quartette of formulæ:



The suggestiveness of these symbols can hardly be questioned. All four are covered by the one general hypothesis; and tourmaline, furthermore, is known to alter into muscovite.

Leaving the aluminous salts, the other silicates present few structural difficulties. Isomorphous mixtures become perhaps more common, but when they are resolved into their constituents relatively simple compounds are found. The commoner bivalent metals form both ortho- and

metasilicates, and to them the substitution hypothesis, as a rule, easily applies. Only in the metasilicate series do we find notable difficulties and they may be avoided by the assumption of polymeric molecules. Thus, instead of $R''SiO_3$, we should write $R''_2(SiO_3)_2$, in which one atom of R'' becomes replaceable. This conception is by no means new, and is indeed quite commonly in use; but I may be permitted to cite one item of evidence in its favor. When solutions of calcium chloride and sodium metasilicate are mixed, a white precipitate of calcium metasilicate is thrown down. This reaction I have studied under various conditions of temperature and concentration, and I find that when the precipitated salt is carefully dried over sulphuric acid it has the composition $2CaSiO_3 \cdot 5H_2O$. That is, the double molecule $Ca_2Si_2O_6$ is required in order to avoid a formula containing a half molecule of water. By itself this fact is not of weighty importance, but it counts for something in confirmation of the prevalent views.

Concerning mixed silicate molecules, partly ortho- and partly metacompounds, I have nothing at present to say. Such silicates undoubtedly exist, as well as aluminous silicates derived from normal salts of magnesia or lime. Nor do I venture to assert that all known silicates are as yet interpretable by simple structural means. There are many outstanding cases which still seem very obscure, but which I confidently expect will be cleared up in time. The micas, chlorites, and scapolites especially need a great deal of further study. Various theories have been proposed to account for the composition of these groups, but not one is absolutely conclusive and satisfactory. The new method of discussion which I have proposed is yet to be fully applied to these minerals but a wider knowledge of their variations is essential to its complete application. Whether the method shall be finally established as valid remains to be seen, but its results so far at least entitle it to respectful consideration. As a working hypothesis the substitution theory has value, even though it should be ultimately overthrown.

In conclusion, there is one question to be considered. With the silicates the supposition that double salts are substitution derivatives of normal salts appears to work exceedingly well. But how about double salts in general? With such compounds as the sulphates, chromates, tartrates, oxalates, etc., there seem to be few difficulties; but with the double haloids, acetates, formates, etc., the case is not so clear. Their explanation is troublesome, at least in accordance with current views concerning the valency of their acid radicles; but those views are not absolutely incapable of modification. There may be exceptions to the general hypothesis of derivation, but chemists are not likely to be satisfied with partial theories, and all double salts ought to come under one common law. Toward that ultimate purpose the present paper tends, even though the road which it opens may not reach the final goal.

SOME NICKEL ORES FROM OREGON.

By F. W. CLARKE.

In or about the year 1881 extensive deposits of nickel silicates were discovered in Douglas County, Oregon. In appearance the ores are identical with the so-called "garnierite" and "noumeaite" of New Caledonia, and many specimens bearing these names have found their way into collections of minerals. At present the deposits at Riddle, Oregon, are being worked by the Oregon Nickel Company, and, through the kindness of Mr. Will Q. Brown, an admirable series of the ores was recently sent to the United States Geological Survey for investigation. According to Mr. Brown all the deposits lie at or near the surface, in beds from 4 to 30 feet thick. Mining is carried on through open cuts or quarries, and no second bed has ever been found underlying the first.

The specimens at my disposal represent a wide range of appearances. They include samples of the country rock and of the associated chromite, and the nickel silicates themselves vary much in color and texture. The finest specimens are bright apple-green and quite compact, and from this they range through duller shades into masses of distinctly earthy texture. Most of them are intermixed with oxides of iron and with quartz; and even the purest mineral, like the garnierite of New Caledonia, is seamed with thin sheets of chalcedony. All of the nickel bearing samples are much decomposed; and one particularly beautiful specimen is distinctly a conglomerate or breccia, having nodules of the green ore imbedded in it side by side with pebbles and fragments of other material. Like all the nickel silicates which have been so far observed in nature, these ores are unmistakably products of alteration, and the problem of their genesis is somewhat interesting. For comparison with them I had a suite of the New Caledonia minerals, received from Professor Liversidge, and a large series of the genthites from Webster, N. C., collected by Mr. W. S. Yeates. All three localities have much in common, and the three sets of specimens point clearly to one conclusion, which will be stated farther on after the evidence for it has been presented.

In composition the nickel silicates from any locality vary widely; for the earthy nature of the material renders it impossible to secure anything like a homogeneous substance for analysis. The purest

specimen of the Riddle ore was dark apple-green, compact, and amorphous; but so permeated with films of silica that a definite mineral could not be isolated. With the best material obtainable I secured the following results, which I give side by side with two published analyses by Hood,¹ in order to show the variations.

	Clarke.	Hood.	Hood.
Loss at 110° C	8.87 ₂		
Loss on ignition	6.99 ₅	6.63	7.00
Al ₂ O ₃ + Fe ₂ O ₃	1.18	1.38	1.33
SiO ₂	44.73	48.21	40.55
MgO	10.56	19.90	21.70
NiO	27.57	23.88	29.66
	99.90	100.00	100.24

Neither lime, sulphates, chromium nor cobalt could be detected. Like the New Caledonia garnierite, the fragments of this silicate fell to pieces when immersed in water.

Of the New Caledonia silicates many analyses have been published, notably by Liversidge and Leibius, Typke, Damour, Garnier, and Ulrich, and they vary between widely separated extremes. Not only are there the variations due to mutual replacements of nickel and magnesia, with a range in the percentage of NiO from 0.24 to 45.15 per cent, but there are also great differences in silica and in hydration. It is therefore impossible to say whether we have to deal with one nickel salt, varying only in its impurities, or with several compounds, although the general similarity of the material from different localities renders the former supposition the more probable. According to Ulrich² the noumeaite and garnierite consist of a soapstone-like base, with a hydroxide or silicate of nickel distributed through it in veins and patches; while Des Cloizeaux³ regards noumeaite as a magnesian hydrosilicate impregnated with nickel oxide. The latter view, however, is hardly probable, especially when we consider the origin of the minerals; and Typke⁴ has cited evidence against it. The prevalent opinion, that we have to deal with one or more definite hydrosilicates of nickel, is best sustained by careful comparative study of the specimens, even though the salts may not be obtained pure or positively formulated. The reciprocal variation of nickel and magnesia in more than twenty published analyses excludes from further consideration the idea that the nickel is present to any great extent as hydroxide. For temporary convenience we may use the well-recognized name "genthite" generically, and apply it to all the nickel silicates from the above-named localities.

¹ Mineral Resources of the United States, 1883.

² Amer. Journ. Sci., Third series, vol. 11, p. 235.

³ Bull. Soc. Min., 1, 29.

⁴ Chem. News, 34, 193.

the "country rock" surrounding the Oregon beds one large, clean, specimen was received. This was subjected to analysis, and also, through the kindness of Mr. J. S. Diller, to careful microscopic study. Olivine separated from it by Mr. Diller was analyzed also, although material was not absolutely free from enstatite and chromite, and analyses are here presented together.

	Rock.	Olivine.
Ignition	4.41	.57
SiO ₂	41.43	42.81
Al ₂ O ₃	.04	.....
Cr ₂ O ₃	.76	.79
Fe ₂ O ₃	2.52	2.61
FeO	6.25	7.20
NiO	.10	.26
MnO	none	none
CaO	.55	none
MgO	43.74	45.12
	99.80	99.36

will at once be seen from these data that the rock contains nickel, and that the olivine separated from it contains even a larger proportion. This fact suggests a probable source of derivation for the nickel in the Oregon beds of ore, and this view is maintained by the microscopic investigation. Concerning the latter, Mr. Diller reports as follows, describing both the rock and the genthite:

The high specific gravity and dark yellowish green color of the country rock with the genthite is associated at Riddle, Oregon, at once suggests that it belongs to the peridotites, and such it is proved to be by investigation. It is a holocrystalline igneous rock, composed essentially of olivine and enstatite with a small percentage of accessory chromite and magnetite. The olivine predominates, so that the genthite forms less than one-third of the mass. Both of these minerals are clear and colorless, but may be readily distinguished by their cleavage and optical properties. They are allotropic, i. e. not bounded by crystallographic planes, and do not show prominent inclusions, excepting a few grains of chromite and magnetite and some siliceous dust. Notwithstanding the comparatively fresh condition of the rock, to which according to Wadsworth, the name Saxonite may be applied, it is completely altered by a multitude of cracks filled with serpentine resulting from alteration. It also results from the metasomatic changes in the saxonite, and wherever the genthite occurs it is always associated with either quartz or serpentine.

The genthite from Oregon varies in color from green to pale apple or yellowish in reflected light, and is compact with a faint suggestion of fine granular structure. Generally it is dull, but where most compact and traversed by a series of fine fissures or seams of quartz it has a decidedly waxy luster. Under the microscope it usually appears to be an aggregation of irregular grains which have in transmitted light a pale yellowish green to coffee-brown color, and a peculiarly clouded aspect. Where the grains are very thin the genthite may be said to be transparent and isotropic, but the majority of them are only translucent. In the narrow veins of genthite lying between seams of quartz the former is indistinctly fibrous and doubly double refracting; but its system of crystallization could not be definitely ascertained. In small veins it is free from grains of other minerals, but elsewhere it

is very intimately commingled with quartz. The relation of the two minerals is shown in the accompanying Fig. 1, in which the shaded portions (3) are genthite,

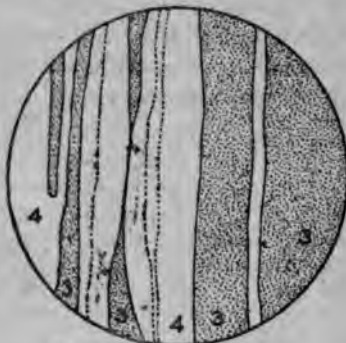


FIG. 1.—Genthite and quartz.

and the clear ones (4) are quartz. The commingling of the two minerals is so intimate as to make it evident that both were deposited from solution in circulating waters. Veinlets of quartz are frequently found cutting across those of genthite, and in general it appears to be true that the latter mineral was laid down first, although it is probable that both were precipitated at about the same time. Although the purest genthite is to be found with quartz, the mineral is more commonly associated with serpentine; and this relation is a most important one in its genetic significance. The accompanying Fig. 2 represents the edge of one of the larger veins of genthite (3),

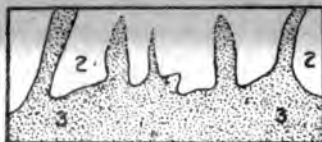


FIG. 2.—Genthite and serpentine.

with numerous veinlets or fissures extending out into the serpentine (2). The tributaries are abundant on both sides of the vein. Fig. 3 shows a vein of genthite (3) in

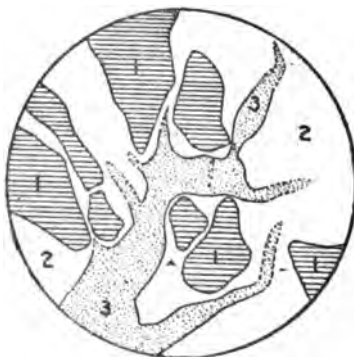


FIG. 3.—Genthite and serpentine with oxide of iron.

the serpentine (2), which envelopes small masses of residuary oxide of iron (1), left by the decomposing olivine. The area represented is only 0.64 of a millimeter in

iameter and contains no olivine; but less than half a millimeter from the boundary of the vein much olivine still remains, although deeply coated with oxide of iron and serpentine. The branching starting from the vein of genthite, together with the manner in which the arms gradually fade away into the serpentine at once suggests the source from which the genthite has been drawn. The genthite and serpentine are thoroughly intermingled, but the former is generally present in such small quantities as to be overlooked unless it is the object of special research. It occurs in the serpentine directly connected with the grains of olivine from which the serpentine has been derived, and there is every reason to believe that the genthite came from the same source.

In order to secure completer confirmation of the idea that the nickel of the greater silicate deposits is derived from the alteration of nickeliferous olivine, Mr. Diller, at my request, also examined specimens from Webster, N. C., and from New Caledonia. Concerning the Webster genthite Mr. Diller reports that—

It is almost identical with that from Oregon, excepting that it is not so thoroughly intermingled with quartz. The relation of the genthite to the serpentine and the olivine at the Webster locality is exactly the same as at Riddle. The rock at Webster differs slightly from that at Riddle in containing a smaller proportion of enstatite, and belongs to the peridotites to which the name "dunyte" has been applied.

He also finds the New Caledonia mineral to be identical with genthite in its physical properties, and says:

Under the microscope it varies from pale yellowish green to light coffee-brown, and is either completely isotropic or exhibits only faint aggregate polarization. Like the genthite of Oregon it is deposited in layers and cavities thoroughly intermingled with quartz, and in the same thin section may be seen serpentine with traces of olivine and enstatite so disposed as to clearly indicate that the serpentine, noumeaite, and other secondary products have resulted from the alteration of peridotite.

This observation confirms the earlier one of Des Cloizeaux (*loc. cit.*) who stated that the noumeaite was imbedded in a serpentine rock which appeared to be derived from olivine, and which contained crystals of the latter mineral plentifully disseminated through it. A similar suggestion is made by Mr. H. J. Biddle,¹ who regards the nickel of the Webster deposits as an original constituent of the olivine rock, and cites an experiment of Mr. G. B. Hanna, who found 0.15 per cent. of nickel oxide in a chrysolite from Waynesville, N. C.

So far, the case appears to be clearly and conclusively settled as to the origin of the nickel silicates under discussion. Nickel is almost always present in small quantities in olivines, and T. Sterry Hunt, in reporting genthite from Michipicoten Island² calls attention to the fact that the metal is rarely absent from the serpentines, steatites, diallages, and actinolites of the Quebec group. Nevertheless, one other possible source of nickel must be noticed. Roth,³ in speaking of the genthite from the chrome mines of Pennsylvania, attributes it to the alteration of nickeliferous chromite; and the almost universal association of the

¹ Mineral Resources of the United States, 1886.

² Report Geol. Survey of Canada, 1863, p. 506.

³ *Allgem. und Chem. Geologie*, vol. i, p. 225, 1879.

latter mineral with genthite, renders the view deserving of attention. But it must be remembered that chromite alters with great difficulty, while olivine decomposes with extreme ease; and moreover the genthite from Oregon contained no chromium, although that metal was diligently sought for. Furthermore, Mr. Diller examined some of the chromite from the Riddle mines, and found that although it was penetrated by crevices filled with secondary minerals containing genthite, the chromite itself showed no evidence of alteration.

Concerning the other silicates of nickel, described under the names of pimelite, alipite, conarite, röttisite, rehdanskite, etc., little need here be said. Some of them are probably similar in origin to the better known genthite, although the conarite and röttisite, which contain small amounts of sulphur and arsenic, probably came from nickeliferous sulphides. For the other minerals above named there is too little evidence upon record to warrant any serious attempt at discussion.¹

¹ A full discussion of the nickel silicates from New Caledonia may be found in Professor Liversidge's work, entitled "The Minerals of New South Wales, etc.," published by Trübner & Co., in 1888.

NATURAL SODA; ITS OCCURRENCE AND UTILIZATION.

By THOMAS MAREAN CHATARD.

The enormous consumption of carbonate of sodium in consequence of the great variety of uses to which it is applied in manufactures and daily life, has made its artificial production one of the most thoroughly developed branches of chemical technology. The valuable work of Lunge,¹ which is the standard authority on this subject, gives the history of this industry from its slender beginnings to its present vast expansion and shows what energy, ability and capital have been expended in the course of its development.

Of the many methods proposed for the manufacture of carbonate of sodium, but two, the Le Blanc and the ammonia processes, have fulfilled practical requirements and are, at present, contending together for the mastery of the field. So sharp is this competition that in many cases

the Le Blanc process can live only through the demand for its by-products—the soda obtained yielding little or no profit—and if the problem of the utilization of the chlorine in the waste liquors of the ammonia process be ever economically solved, the former method must soon become a thing of the past.

Before the discovery of the Le Blanc process the only sources of carbonate of sodium were barilla, or the ashes of certain plants, and a small amount of "trona" or "natural soda" obtained from Hungary and a few African localities. The principal use of soda is in the manufacture of hard soaps, which, in default of this alkali, can be made by adding common salt to the "soft soap" produced by saponification of fats by means of the potash-lye obtained by the leaching of wood ashes. The addition of salt causes the soap to curdle, the sodium of the salt displacing the potassium of the "soft soap" while the residual liquid retains chloride of potassium. Such was the method of soap-making followed at that time, but the increasing cost of potash and of barilla gave a powerful impulse to the artificial soda manufacture which abroad has now become the most important branch of chemical industry.

¹ Sulphuric Acid and Alkali, by George Lunge. Ph.D., three vols., London, 1880.

Nature has been bountiful in giving us, within our boundaries, sources of soda which await the union of capital and technical skill to become valuable producers of national wealth. These sources of natural soda are the alkaline lakes and "dry deposits" situated in that section of the country lying between the Rocky Mountains and the Sierra Nevada, known as the "Great Basin." Many are well known, having been described by the various Government expeditions and surveys; while some are too weak, too impure, or of too little extent to have a prospective value, others promise good results to well-directed practical development. To aid this, the present investigation has been undertaken by the United States Geological Survey.

This work naturally falls into two divisions—the collection and arrangement of previously existing knowledge and a study of the technical questions involved. As the literature of the subject consists of but few articles, most of which are to be found only in journals inaccessible to those more particularly interested, it has been deemed advisable to bring together, in a compact form, the information we possess concerning foreign localities, both as to their nature and the work done in connection with them. In regard to the study of the technology of the subject, it must be understood that this has its special difficulties, since laboratory experiments on a small scale, no matter how carefully conducted, can rarely reproduce the condition existing in large masses of such material, while the influence of the climate is also a very potent factor. For these reasons a portion of the work was done in the field, and more was contemplated, but unforeseen circumstances have prevented the complete prosecution of this plan, and the results so far obtained are published in order that others may be induced to take up the work and develop it on a practical scale.

COMPOSITION.

"Natural soda," so called to distinguish it from the soda produced by artificial processes, is the residue obtained by the evaporation of alkaline waters, without the aid of artificial heat. It is composed of sodium carbonate and bicarbonate, in varying proportions, mixed with impurities, mainly sodium chloride and sulphate. In comparing natural sodas from different localities we shall find that they vary widely in composition, so that a process of manufacture developed in one locality, and yielding there a very pure and cheap product, may fail completely when applied without proper modification to the material from another place.

The problem to be solved is the economical production of commercial sodium carbonate by the appropriate treatment of the natural soda, and the means to be employed are, in the main, solution, evaporation and fractional crystallization. By fractional crystallization we mean a methodical stoppage of the crystallizing process by removal of the remaining solution or "mother liquor" from the "crop" of crystals so far

obtained. This "first crop" may be either the desired material in a purer condition than it was in the original solution or may consist mainly of impurities which we wish to remove.

As the first step in this study it is necessary for us to know the nature and properties of the salts composing natural soda, not only when they are pure, but also when in combination with each other, since the properties and reactions of each salt are modified by the presence of the others in its solution, and the extent of this influence is generally proportionate to the relative amounts of the salts present.

The substances to be considered are, therefore, sodium sulphate, chloride, carbonate and bicarbonate, and in describing them only those characteristics which seem to be of interest in this connection will be mentioned, since the text-books of chemistry, notably the work ofunge already mentioned, give all needed general information with sufficient fullness.

SODIUM SULPHATE.

Sodium sulphate Na_2SO_4 , or anhydrous sodium sulphate, is found in nature as the mineral Thenardite. Combined with ten molecules of water of crystallization or $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, it forms the mineral Mirabilite. Both of these minerals, as also the artificial sulphate, are soluble in water, and the solution on being evaporated yields, according to the emperature and other conditions, either anhydrous salt or salt with even or ten molecules of water of crystallization.

The composition of these salts is as follows:

	Anhy- drous.	With 7 H ₂ O.	With 10 H ₂ O
Na ₂ O	43.67	23.13	19.25
SO ₃	56.33	29.85	24.84
H ₂ O		47.02	55.91
	100.00	100.00	100.00

Of the two hydrated salts, the one with 10 H₂O is generally known as crystallized Glauber's salt, and is formed when the solution is evaporated under ordinary conditions. It forms large transparent crystals which effloresce in the air, falling into a white powder and losing all of the water if the air is sufficiently dry. If, however, the solution is made strongly alkaline, by the addition of sodium carbonate, and evaporated at ordinary temperature, the crystals then obtained are anhydrous.¹ That the sulphate is under such circumstances anhydrous is also shown by the numerous analyses of mixed salts given in this paper, notably those on pages 63, 64, as the amount of water there found is insufficient for even the salt with one molecule of water of crystallization or $\text{Na}_2\text{SO}_4 \cdot \text{H}_2\text{O}$, said by Thomsen² to be formed under such conditions.

¹Schulz-Sellack: Journ. für prakt. Chem., series 2, vol. 2, p. 459.

²Thomsen: Ber. Deutsch. Chem. Ges., vol. 11, p. 2042.

The solubility of this salt in water increases with the temperature, 100 parts of water at 0° (32° F.) dissolving 5.02 parts Na_2SO_4 , while at 33° C (91.4° F.), the point of greatest solubility, 50 parts Na_2SO_4 are dissolved. As different observers give different results it is well to state at this point that the solubility of a salt at any given temperature depends on whether we take the salt in its anhydrous condition or as combined with water of crystallization. The experiments of Loewel¹ show this very clearly for sodium sulphate, and it is also true for sodium carbonate. Of course the figures are only true for pure solutions; if other salts are present such as chlorides and carbonates the question becomes very complicated. The results obtained by the series of experiments on the evaporation of Owens Lake water, to be described later, may, however, aid us in forming correct conclusions, but so far we can only say that, from a practical point of view, the sodium sulphate which is always present to a greater or less extent in all alkaline waters and dry deposits is a most unwelcome guest, being of itself comparatively worthless, but by its presence greatly complicating any process devised for the extraction of the valuable carbonate. As will be seen later it is deposited to some extent with the "first crop" of crystals, even when this crop represents but a small portion of the total salts in solution, and, unlike sodium chloride, it has a distinctly deleterious effect upon the quality of the product. It must, therefore, be the aim of the manufacturer to prevent, or at least to control, its deposition as far as practicable, and to attain this result careful and judicious work will be necessary.

SODIUM CHLORIDE.

Sodium chloride (NaCl) or "common salt," contains 39.39 per cent. sodium and 60.61 per cent. chlorine. It crystallizes in cubes which, when the crystallization occurs on the surface of the solution, usually unite together to build up the well-known "hopper forms." The crystals formed on the bottom are generally incompletely developed, but sometimes, and this is particularly the case when certain other salts are present, the cubes are perfectly formed, transparent and very bright. Other crystal forms and modifications have also been observed.

One hundred parts pure water at 0° C (32° F.) dissolve 35.59 parts NaCl , and this solubility is but little increased by a rise in temperature as at 30° C (86° F.), only 36 parts are dissolved. Even at the boiling point of the saturated solution 109.7° C (229.5° F.) it contains but 40.35 parts. This peculiarity of solubility is of great importance in the practical treatment of the natural soda, since it renders the removal of the chloride a comparatively easy matter, the rate of deposition of the salt being but little influenced by changes of temperature of the solution.

If deposited with the crop it has no other effect than to reduce the percentage of alkali, and therefore the market value of the product,

¹ Loewel: *Ann. Chim. et Phys.*, series 3, vol. 49, p. 32.

while its presence in the solution up to a certain proportion appears to have a distinctly beneficial action as causing a more complete and satisfactory crystallization of the first crop.

The influence of chloride of sodium on the solubility of carbonate of sodium will be shown under the latter head by the tabulated results of experiments undertaken to determine it.

SODIUM CARBONATE.

Sodium carbonate or sodium monocarbonate Na_2CO_3 is composed of—

	Molecular weight.	Per cent.
Soda, Na_2O	62.0	58.53
Carbonic acid, CO_2	44.0	41.47
	106.0	100.00

It is an opaque white salt of a specific gravity of 2.5, and melts at a moderate red heat, losing a small portion of its carbonic acid, this loss occurring even when the salt is heated and cooled in a stream of dry carbonic acid. When fused in a crucible over an ordinary flame the loss of weight at a red heat is about six-tenths of 1 per cent.; as the heat increases so does the loss, so that at a yellow heat up to 1.75 per cent. is lost, but this is regained as the material cools, so that the final loss is that at a red heat. If the salt is fused in a current of air or of steam, the loss is continual and proportioned to the degree and duration of the heating, experiments giving a loss as high as 2.05 per cent.¹ A solution of sodium carbonate, if boiled, undergoes a small but continued loss of carbonic acid, and the same loss occurs if the solution is placed in a vacuum at ordinary temperatures. (Jacquelain.)

Sodium carbonate dissolves in water with evolution of heat. From its solution it crystallizes with 1, 2, 3, 5, 6, 7, 10 and 15 molecules of water; (1) according to the temperature of the solution, and (2) according to whether the solution, prepared at a boiling heat, in cooling down is freely exposed to the air or not.

Of these hydrates the monohydrate ($\text{Na}_2\text{CO}_3\text{H}_2\text{O}$), is found in nature as the mineral thermonatrite; "the trihydrated salt ($\text{Na}_2\text{CO}_3, 3\text{H}_2\text{O}$), according to Schickendantz, is found as an efflorescence in dry places of the beds of rivers in the Cordilleras;" while the decahydrate ($\text{Na}_2\text{CO}_3, 10\text{H}_2\text{O}$), which is the ordinary "crystal soda" of commerce, has been found native by Olzewsky.³ The anhydrous carbonate Na_2CO_3 also seems to occur, as Kayser⁴ describes an incrustation which had evi-

¹Scheerer: Ann. d. Chemie u Pharm., 116, p. 129; Mallard: Ann. de Chimie, series 4, vol. 28, p. 89; Jacquelain: Ann. de Chimie, series 4, vol. 32, p. 193.

²Lunge: Sulphuric Acid and Alkali, vol. 2, p. 277.

³Olzewsky: Journal für prakt. Chemie, vol. 102, p. 375.

⁴Kayser, W.: Liebig's Jahresbericht der Chemie, 1850, pp. 759, 821.

dently been formed by the weathering of the clay slate upon which it was found. His analyses of both slate and incrustation are given and are interesting as bearing on the problems of rock decomposition and as showing one of the ways in which "natural alkali" is produced.

	Slate.
SiO ₂	49.87
Al ₂ O ₃	26.41
Fe ₂ O ₃	6.95
Mn ₂ O ₃	1.21
CaO	2.10
MgO	.87
K ₂ O	2.96
Na ₂ O	1.61
Sulphur	.39
Carbon	.65
H ₂ O	7.05
BaO	11.
	100.27
	Incrustation.
FeCO ₃	.19
MgCO ₃	3.32
CaCO ₃	1.81
Na ₂ CO ₃	92.07
H ₂ O	1.85
	99.24

Sodium carbonate is most soluble, according to Mulder, in pure water at 32.5° C (90.5° F.), the solution then containing 59 parts Na₂CO₃ to 100 parts water, or 37.10 per cent. Hence a solution which has deposited crystals at the boiling point (105° C—221° F.) redissolves them while cooling till the temperature sinks below 32.5° C, when recrystallization begins. The solubility varies very greatly with the temperature; thus at 15.5° C (60° F.) the saturated solution contains 14.53 per cent. at 31.3° C, 30.04 per cent. and at 32° C, 31.78 per cent.

The presence of sodium sulphate or chloride decreases the amount of carbonate which a given amount of water can dissolve, and as the nature and extent of this influence is of importance in studying the conditions attending the separation of the carbonate from the natural deposits and solutions, all of which contain chlorides usually in larger proportions than carbonates, three series of experiments have been carried out and the results are given in the following table.

In series A the NaCl was dissolved in water and the solution was made up to 50cm³. The Na₂CO₃ was then added and the whole shaken vigorously, the shaking being repeated at intervals throughout the day. The graduated cylinders containing the solutions were allowed to stand till the next morning, when the mother liquors were filtered from the deposited salts, a perforated crucible with asbestos felt being used for this purpose.

volume and temperature of the filtrate were noted, and 25 cm³ taken for the determination of the specific gravity. This portion then diluted with water to 1000 cm³, and of this dilute solution portions of 50cm³ each were taken for the determinations. These portions as well as the 1000 cm³ were in all cases weighed, and the results have been calculated by the factors so found.

For series B the operations were the same, except that the Na₂CO₃ dissolved first, the NaCl being added, in portions of 2.5 grams a permanent deposit was formed, while for series C a saturated or liquor of Na₂CO₃, 10H₂O was employed, 50cm³ being taken for portion.

no. a.	In 50cm ³ .		°C.	Sp. G.	Percent. Na ₂ CO ₃ .	Average.	Percent. NaCl.	Average.	Total per cent. of salts.
	Na Cl. grams.	Na ₂ CO ₃ added.							
1.....	Saturated.	5.0	34.0	1.245	7.88 7.92	7.90	21.26 21.24	21.125	29.150
2.....	12.5	10.0	35.5	1.294	14.83 14.87	14.85	17.29 17.24	17.265	32.115
3.....	10.0	15.0	32.5	1.314	18.34 18.36	18.35	14.39 14.37	14.38	32.73
4.....	7.5	17.5	33.0	1.329	22.30 22.26	22.28	10.54 10.51	10.525	32.805
5.....	5.0	20.0	33.0	1.340	26.36 26.36	26.36	7.01 7.02	7.015	33.375
6.....	2.5 Na ₂ CO ₃ grams.	22.5 NaCl added.	33.5	1.352	29.34 29.31	29.325	3.42 3.42	3.42	32.745
7.....	12.5	12.5	35.0	1.309	16.67 16.66	16.665	15.46 15.45	15.455	32.120
8.....	10.0	12.5	35.5	1.281	14.01 13.99	14.00	17.38 17.39	17.385	31.385
9.....	7.5	15.0	32.3	1.261	10.48 10.48	10.48	19.67 19.65	19.665	30.145
10.....	5.0	15.0	32.5	1.237	7.14 7.15	7.145	21.41 21.43	21.42	28.565
11.....	2.5	17.5	33.0	1.217	3.67 3.68	3.675	24.07 24.06	24.065	27.740
12.....	Saturated	none	31.3	1.3287	30.07 30.02	30.045			30.045
13.....	do	5.0	36.0	1.3435	26.59 26.60	26.595	7.20 7.27	7.265	33.860
14.....	do	7.5	29.5	1.3114	19.415 19.417	19.416	13.08 13.08	13.08	32.496
15.....	do	10.0	29.5	1.3139	18.59 18.60	18.595	14.62 14.62	14.62	33.215
16.....	do	12.5	31.0	1.3146	18.81 18.84	18.825	14.48 14.46	14.47	33.395
17.....	do	15.0	30.0	1.3204	19.29 19.30	19.295	14.17 14.15	14.16	33.455

In each of the experiments here tabulated, with the exception of C1 there was a considerable deposit of salts consisting of a mixture, in varying proportions, of the two salts employed, and the composition of the deposit can be calculated by the difference between the amounts originally taken in each case and those in solution.

It will be observed that in the A series the point of equilibrium in the percentages of the two salts in solution lies between A2 and A3, probably near to the point where equal weights of NaCl and Na_2CO_3 would be taken. This is substantially proved by B1 where 12.5 grams of each salt were used and the amount of Na_2CO_3 was 1.21 per cent. higher than that of the NaCl.

The salts, however, do not appear to dissolve in proportion to the amounts taken, the variations being greatest in the A series where the Na_2CO_3 was added to the solution of the NaCl; whereas in the B series, the Na_2CO_3 was first dissolved and the NaCl added the variations are much smaller. We may therefore conclude that if a mixture of these two salts is treated with an amount of water insufficient for complete solution, the amount of each dissolved will be approximately proportionate to the quantity present but that the approximation is not very close.

Series C shows the effect of the addition of increasing proportions of NaCl to a saturated solution of Na_2CO_3 . 50cm³ of this solution at 31.3° C. weighs 66.3424 grams and contains 19.9224 grams Na_2CO_3 , or, as given in the table, 30.045, per cent. The table shows that the addition of 7.5 grams NaCl gave the best result, but as some of it remained in the deposited Na_2CO_3 , a less quantity might have been advantageously taken, say 6.64 grams or one-third of the weight of the Na_2CO_3 in solution. Had this been done we should probably have had little more Na_2CO_3 left in solution and that deposited would have been purer. If the amount of NaCl is increased, the excess as shown, remains undissolved and the character of the solution suffers but little change. The practical bearing of these results will be more apparent when we come to that portion of this paper treating of urao or the combination of sodium monocarbonate with sodium bicarbonate.

SODIUM BICARBONATE.

Sodium bicarbonate, NaHCO_3 , contains—

	Per cent.
Soda, Na_2O	36.94
Carbonic acid, CO_2	52.36
Water, H_2O	10.70
	100.00

It is formed by the action of CO_2 on Na_2CO_3 , hence is always produced when a solution of the latter salt is exposed to the air. At the ordinary pressure of the atmosphere the reaction is a slow one, but if pure CO_2 at a pressure of 30 pounds to the square inch is used the conversion is rapid.

The salt occurs in monoclinic tables usually combined into crusts. It has a somewhat alkaline taste; if entirely free from Na_2CO_3 it does not change turmeric, but reddens blue litmus. The best test for its purity, according to Hager, is calomel; 0.5 gram calomel mixed with 1 gram NaHCO_3 and 1.5 gram water and shaken up does not blacken in 24 hours in the absence of monocarbonate, but in its presence it turns more or less gray. In moist air or if moistened with water the salt loses CO_2 , the more quickly the higher the temperature. Hence if a solution of bicarbonate is heated the bicarbonate is gradually destroyed and monocarbonate remains, which has an important bearing upon the problem of the economic treatment of natural soda.

NaHCO_3 is much less soluble in water than Na_2CO_3 , 100 parts of water at $15.5^\circ (60^\circ\text{F})$ dissolving only 8.9 parts or 8.17 per cent. The solubility is much diminished by the presence of sodium chloride or sulphate, or a mixture of both. A saturated solution of sodium chloride dissolves hardly any of the salt, a fact of great importance, since upon it is based the ammonia process for the manufacture of soda.

SODIUM SESQUICARBONATE.

Sodium sesquicarbonate, $\text{Na}_4\text{H}_2\text{C}_3\text{O}_9$, so called because the old dualistic formula was $(\text{NaO})_2(\text{CO}_2)_3$ is described in all chemical works which treat the subject of the sodium carbonates at all fully. It is said to exist in nature as a mineral to which the name trona has been given and has been prepared artificially by R. Hermann¹ and Winkler.² Other chemists also claim to have obtained it. It represents a combination of one molecule of Na_2CO_3 with two molecules of NaHCO_3 or $\text{Na}_2\text{CO}_3, 2\text{NaHCO}_3$, which may also be written $\text{Na}_4\text{H}_2\text{C}_3\text{O}_9$. My own experiments, which will be given in detail further on, not only failed in reproducing this salt, but also throw considerable doubt upon its actual existence as a definite chemical substance, and not as a mixture of the two carbonates accidentally formed in these proportions.

There is, however, a very definite combination of the two carbonates, which occurs, as will be shown, widely distributed in nature and which bears the mineral name *trona*. This salt is composed of one molecule of sodium monocarbonate and one of sodium bicarbonate, plus two molecules of water of crystallization, or $\text{Na}_2\text{CO}_3, \text{NaHCO}_3 + 2\text{H}_2\text{O}$, or $\text{Na}_3\text{HC}_3\text{O}_6, 2\text{H}_2\text{O}$. It is very easily produced artificially, in a well crystallized condition, and is most important in this connection, since by its chemical behavior it gives the key to a rational economic process whereby the natural sodas can be made available for use in the arts.

For this reason it will be made the subject of a special section of this paper, but before taking it up we will briefly consider the principal localities of natural soda throughout the world and the character of the salts produced by them. In this manner a better idea of the extent

¹ R. Hermann: Jour. für prakt. Chemie, vol. 26, p. 312.

² Winkler: Buchner's Repert. für Pharm., vol. 43, p. 215.

and difficulty of the problem can be obtained, while a mass of matter at present scattered through the various journals is brought together for comparison.

LOCALITIES AND MODE OF OCCURRENCE.

As a dry climate is the prime factor for the formation of deposits of natural soda, or of concentrated waters heavily charged with it, and as such climatic conditions exist in many parts of the world, there are numerous places where this material has been found or may reasonably be looked for. A complete list of these occurrences is not available, nor would it have any special value, and in speaking of the foreign localities only those will be described where the material is being utilized or where the local conditions are of interest for comparison with our home sources of supply.

HUNGARY.

In Hungary natural soda is found in many places, especially near the town of Szegedin.¹ It occurs as an efflorescence on the surface of moist places, the snow-white crust often extending for miles. The crude soda or "szekso" is collected by scraping the surface, the best time for this operation being the early morning before sunrise, particularly in the spring and when much dew has formed, as the material collected during the day is considered to be poorer in salts. As the crust is thin and much of the soil is gathered with it, the product is a grayish white earth; this is sold to the refiners, whose only test for its value was, at the date of the description, the sharpness of the taste. Moser² gives the following analysis of the szekso as gathered:

Soda, Na ₂ O	8.03
Potash, K ₂ O	3.12
Lime, CaO	2.72
Magnesia, MgO	Trace.
Alumina, Al ₂ O ₃	2.33
Sulphuric acid, SO ₃	3.48
Silica, SiO ₂	1.04
Water, H ₂ O	15.50
Insoluble (sand, etc.)	54.99
Carbonic acid, CO ₂	8.79
	100 00

In the refineries the earth is leached until the soda taste is no longer perceptible, giving a dark-brown solution containing sodium carbonate, sulphate, and chloride; this is evaporated to dryness and calcined, the mass being ultimately heated to complete fusion, and, when partly cooled, drawn from the furnace. The product when cold is broken up and sent to market.

¹ Werner: A. Jour. f. prakt. Chemie, vol. 13, 1836, p. 127.

² Moser: Liebig's Jahresbericht, 1859, p. 812.

Schapringer¹ gives the following analyses of two samples of this soda. No. 1 is said to have been made by evaporating the leachings and drying the product in the air, while No. 2 is said to have been obtained by calcining No. 1:

	No. 1.	No. 2.
Sodium carbonate, Na_2CO_3	28.87	40.25
Sodium chloride, NaCl	31.00	53.93
Sodium sulphate, Na_2SO_4	.13	.45
Calcium carbonate CaCO_3	.39	1.54
Sand, clay, etc.....	.41	1.45
Water.....	39.04	2.09
Loss.....	.16	.29
	100.00	100.00

It is difficult to understand these analyses, since No. 1, if air-dried, could not contain the amount of water here given, and if calcined could not yield a product of the composition of No. 2 which is, at best, very impure and of but little value. The analysis of the szekso shows no chlorides, which is also remarkable, when we consider the origin of this soda, which has been discussed by Szabo and Moser.² According to them the sandy soil contains a large proportion of soda minerals which decompose through the joint action of carbonate of lime, water, and air. The lime furnishes carbonic acid to the soda which is dissolved in the water with which the ground, in winter, is saturated. As the summer approaches and the ground becomes warmer, the decomposition increases, while the water rising to the surface and there evaporating leaves its salts behind.

Owing to the rude methods of refining, with consequent variations in composition, and the increasing cost of collection, the Hungarian soda has not been able to compete with the artificial product, and now supplies only a limited local consumption in the manufacture of the celebrated Szegedin soap. Its history, however, is interesting, since we have in the West many occurrences of soda similar to those of Hungary, and it would seem at first sight as though they could be utilized; but if in a country of such low wages as Hungary the cost of collection is too great we can hardly look for much success in attempting similar processes at home, unless we can find deposits comparatively pure and of considerable thickness. In default of such, we can expect satisfactory results only from the waters of the soda lakes, in which nature, having performed the leaching process, has collected and concentrated the salts.

¹ Schapringer: Dingler, Polyt. Jour., vol. 189, p. 495.

² Szabo, J., and Moser, J.: Wagner's Jahresber., 1862, p. 223.

EGYPT.

The soda lakes of Egypt have been described by D'Arcet¹ and by Russegger.² They are nine in number, in the Desert of St. Macarius, sixty miles northwest of Cairo and about thirty³ miles from the Nile, and are situated in a small valley running northeast and southwest. The largest, Nehelé, is five miles long by one-and-a-half wide, with a maximum depth of 20 feet. On the eastern side of the valley are a number of weak brine springs (some, indeed, being fresh) which feed these lakes in which, having no outlet, the concentration is continual, varied only by the annual rise and fall. Russegger observed that the lakes rise when the Nile is falling and fall during its rise, and ascribes this partly to the rains which occur during the decrease of the river and partly to the supposition that the rise of the river is sufficient to overflow the divides of the clay formation which underlies the desert sand, and the water then flows through the sand to the lowest points of the valley in which are the lakes. As, however, it takes much time for the water to travel that distance, the lakes are not reached, and therefore do not rise, until the end of the high-water season.

The surface of the country is the desert sand, under which is a layer of blackish-gray clay, 20 feet thick, resting upon a tertiary sandstone. This clay is strongly impregnated with chloride of sodium and carries much gypsum, the quantity of both salts being much greater in the lower than in the upper part; it also contains much carbonate of lime. The gypsum is either scattered in single crystals through the whole mass of the clay, or, especially in the lower part, interstratified with it in thin layers intermixed with desert sand and common salt, forming a kind of gypsum sandstone.

The lakes, formed by the leaching out of the soil, are therefore strong solutions of chloride of sodium containing in addition varying proportions of carbonate and sulphate of sodium. During the dry season the smaller lakes dry up entirely, leaving on the bottom a salt crust of the composition of the entire lake; the larger lakes, on the other hand, do not dry up, but, as they become more concentrated, deposit salt crust, the composition of which depends upon the percentage of carbonate of sodium in the water.

In some of the lakes, bottom deposits are said to have gradually formed whose upper portion, 16 feet thick, consists essentially of sodium chloride, whilst the lower one, 17 feet thick, contains sodium carbonate. The above mentioned crusts, which are 15 to 18 inches thick, are pushed off by means of poles and spades, spread out to dry on the banks, and carried in baskets to the Nile, whence the salt is shipped to

¹ D'Arcet: Comptes rendus, September, 1845, vol. 10. Dingler Polyt. Jour., vol. 98, p. 159.

² Russegger: Karsten's Archiv, vol. 16, 1842, p. 380.

³ Lunge: Sulphuric Acid and Alkali, vol. 2, 1880, p. 285—gives "five miles" as the distance from the Nile. He also quotes "Landerer, Wagner's Jahresb. 1858, p. 68," in this connection, but the volume for that year does not seem on examination to have anything by this author or on the subject.

other parts. It is called "latroni" in the Levant and in Greece; the Egyptians use it to soften their very hard drinking water by precipitating its lime and magnesia salts, the water being afterwards filtered. Its principal use is in Crete for soap making. From Alexandria yearly about 2,500 tons are exported.¹

This soda has been analyzed by Remy,² who describes the sample as bright gray, crystalline, effloresced on surface, slowly soluble in cold water, more rapidly in hot, leaving a little residue partly soluble in hydrochloric acid. The analytical results are as follows:

Sodium chloride, NaCl.....	8.160
Sodium sulphate, Na ₂ SO ₄	2.147
Sodium silicate, Na ₂ SiO ₃	.288
Sodium sesquicarbonate, Na ₄ H ₂ C ₃ O ₆	47.292
Sodium carbonate Na ₂ CO ₃	18.430
Calcium carbonate CaCO ₃	.200
Water.....	19.669
Insoluble.....	4.106

100.292

ARMENIA.

As described by Abich,³ the lakes of the Araxes plain in Armenia lie in the volcanic region of Ararat and show a great variety of composition. The lake of Tasch-Burnn is situated on "the most distant of the lava masses which have broken out at the northwestern base of the Great Ararat," and its water carries 6.66 per cent. of salts, mainly sodium chloride as shown by analysis No. 1. Analysis No. 2 gives the composition of the crusts which are deposited on the shore in hot weather; these attain a thickness of a half-inch and are of a reddish color.

Other lakes are found southeast of Little Ararat among the volcanic lavas of this mountain. One of these lakes, remarkable for the reddish color of its water, lies on the left side of the valley close under the steep declivities of the greatest heights of the Gundusdag range which is formed of sandstone, dolomite, slates, and limestone and is broken through and shattered by a red quartz-porphyry. The surface of the country is a whitish clay, supporting a strong growth of soda plants.

The shore of this lake, which is about a mile in circumference, is very soft, so that walking is difficult, and is covered with crusts of a hard reddish salt having a laminated fracture. The crusts extend out upon the surface of the lake and portions are floating upon it, so that the whole looks as though it were about to freeze. Soundings showed that crusts had also formed on the bottom, apparently covering the whole of it. The water contains 30.63 per cent. of salts, the composition of which is shown by analysis No. 3, while No. 4 is the composition of the bottom crusts, and No. 5 of the floating portions.

¹ Lunge: Sulphuric Acid and Alkali, vol. 2, p. 286.

² Remy: Journal für prakt. Chemie, vol. 57, p. 321.

³ Abich: Jour. für prakt. Chemie, vol. 38, p. 4.

The heavy bottom crusts are described as being composed of successive layers, each of which is a very solid radiated aggregate of crystals; the red coloring matter is deposited between the layers, which adhere closely together. The floating crusts have nearly the same composition and structure, but the layers are much thinner and the salt is almost white. The analyses are remarkable as showing that not only the sulphate but also the carbonate has crystallized almost free from water. Abich concludes that this is due to the formation of a "double salt" of sodium sulphate and carbonate, for which he proposes the mineral name "makite." In the vicinity of this "red lake," are a number of small pools of a wine-yellow color, but without salt crusts. The water of one of these contained 34.74 per cent. of salts of the composition of analysis No. 5. Other lakes are mentioned in the original paper, but the waters were poorer in sodium carbonate and sulphate and richer in sodium chloride.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
	Tasch-Burun.		Red Lake.			Yellow pool.
	Water.	Crusta.	Water.	Crusts.		Water.
				Bottom.	Floating.	
Sodium carbonate, Na_2CO_3	14.71	22.91	12.08	18.42	16.09	68.90
Sodium sulphate, Na_2SO_4	10.36	16.05	18.18	77.44	80.56	15.55
Sodium chloride, NaCl	74.61	51.49	69.73	1.92	1.62	15.50
Water, H_2O		9.88		1.18	.55	
	99.68	100.33	99.99	99.96	98.82	99.95

The views of Abich as to the mode of formation of these salts will be given in the section treating of the origin of natural soda.

OCCURRENCE OF URAO IN VENEZUELA, SOUTH AMERICA.

This locality is described by Palacio Faxar¹ as being in a valley named La Lagunilla in the province of Maracaibo, 48 miles from the city of Merida. In the center of this valley, the soil of which is said to consist of limestone, lies a little lake which in the rainy season has a length of 210 meters and a breadth of 106. Although its greatest depth is not over 3 meters, it never dries up entirely even in the driest seasons. The water is yellowish-green, has a soapy feel, an alkaline taste, and a peculiar smell. During the hot season a salt crystallizes on the bottom. This salt, called urao, is collected every two years by the Indians of the neighborhood, who obtain from 100,000 to 160,000 pounds, according to the demand, which is for the manufacture of *mo*, a dried extract of tobacco used by the natives as a stimulant.

¹Faxar: Ann. de Chimie, ser. 2, vol. 2, p. 432. Also, Pogg. Ann., vol. 7, p. 101.

the Indians obtain the salt by diving for it, and the peculiar manner in which this is done is thus described by Boussingault:¹

To collect the urao, the Indians make an excavation on the bottom of the lake, several meters in extent, and plant therein a stake 14 to 16 feet long, the upper end of which reaches above the surface of the water. When this is accomplished an Indian standing upon this stake places the end of a second one upon the deposit and holds it at a certain inclination. As soon as this is done, a second Indian glides down the first stake, plunges beneath the surface of the water and after the lapse of a few minutes returns with a portion of the salt. According to the information we have received, the deposit of urao, which is not very thick, is covered by a layer of material containing crystals of calcite. Above this is a bed of ooze, one meter in thick-

ness. The excavation spoken of in the beginning of this extract is apparently made for the purpose of removing these upper layers; the crystals so-called calcite were later shown to be gay-lussite $\text{Na}_2\text{CO}_3 \cdot \text{CaCO}_3 + \text{H}_2\text{O}$; and the inclined pole is used to enable the diver in such a dense solution to reach the bottom. Concerning this water, Boussingault very correctly says: "The water of the lake is only slightly saline; animals drink it with pleasure."

As the water is necessarily a strong alkaline mother liquor, often completely saturated, it is evident that this statement is incorrect. Far (loc. cit.), more accurately says of the divers: "Their death is inevitable if they swallow a certain quantity of the water."

He also says that the action of the water reddens the hair of the divers. The Urao is described by Boussingault as "crystallized in prismatic masses arranged in radiating masses; a little softer than calcite. Taste saline; does not effloresce." His analysis is as follows:

Carbonic acid, CO_2	39.00
Soda, Na_2O	41.22
Water, H_2O	18.80
Impurities	98
	100.00

NORTH AMERICAN LOCALITIES.

In the various exploring and surveying expeditions sent by the Government into the region of the Great Basin have to some extent explored and reported upon the alkaline deposits and lakes lying within the range of their labors. Private prospectors, also, recognizing the great value of these salts, have not overlooked them, especially when the development of the borax industry caused every accessible salt-marsh or lake to be scrutinized and tested for that substance. In this region natural soda has been found in many places, but the absence of the necessary transportation facilities has, until lately, rendered any plan for the utilization of the soda a matter of the future.

Within the past few years the railroad facilities through this region have greatly increased and are continually extending, so that some of

¹ Boussingault: Ann. de Chimie, ser. 2, vol. 29, p. 110.

the more promising localities are within easy reach. The consumption of soda in this country is already great and steadily growing larger, and it remains for technical skill, supported by capital, to develop these resources and to convert a hitherto valueless, even obnoxious, material into a source of wealth. That this can be done there is no reasonable doubt; that it will be done should not be doubtful to any one who knows the activity and enterprise of our people. The advantages flowing from a successful prosecution of such an undertaking are reaped not only by the operators, but also by the entire section of country in which the work is carried on, and as, except in some favored localities, nature has not been bountiful to this region, well-directed art must extend its aid.

The expense of the necessary preliminary investigations is considerable, but without these capital can hardly be expected to take any decided steps. A great deal of information, in the aggregate, has been gathered by various observers, but scattered as it is through various publications it is not readily available. It has therefore been deemed advisable to bring this knowledge together so that we may have a proper starting point for future work.

In proceeding to describe the localities within the boundaries of the United States only those concerning which we have reliable information will be considered, and it will be found that their number and variety are great enough to furnish types for any others which future investigators may bring to notice.

Wyoming.—Along the line of the Union Pacific Railway in the Territory of Wyoming are several places where natural soda is found. The best description of these is the following, from a paper on "Glass Materials," by Jos. D. Weeks, published by the Geological Survey in the "Mineral Resources of the United States, calendar year 1885":

The soda property generally known as the "Union Pacific Lakes" lies about 13 miles nearly due south of Laramie and is reached by a branch of the Union Pacific Railway. The property embraces some 2,000 acres, including five "lakes," in all but one of which the soda is solid. The lakes are connected, and seem to drain one into another. All of the soil near Laramie is more or less impregnated with the sulphate of soda, and the common sources, it is believed, are springs, water from which bears large percentages of soda salts.

The physical condition of the soda in the lakes varies much with the season. In wet years the soda is almost fluid, while in dry years, in all but one of the lakes, it is solid and in this one it occurs as a saturated solution. In the solid lakes the soda contains many thin layers of mixed clay and soda. Analysis of a sample of this mixture shows:

Analysis of deposits of soda salts at Laramie, Wyo.

	Per cent.
Iron, lime magnesia.....	22.33
Alumina, soda, hydrochloric and sulphuric acids.....	40.82
Silica	36.85
Organic matter	traces.
	100.00

The soda when taken pure contains large quantities of water, which fact interferes seriously with its employment in the manufacture of sodium hydrate.

Its composition only varies slightly, and the following may be taken as typical analyses:

Average analysis of soda deposits near Laramie, Wyo.

	No. 1.	No. 2.	No. 3.
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Sulphate of soda	44.55	41.41	39.78
Water	54.98	54.79	59.66
Insoluble matter.....	.47	3.80	.56
	100.00	100.00	100.00

These lakes are the only ones from which soda is being taken for use.

The soda works near Laramie were built by the Union Pacific Railway and leased to Mr. Howard Hinckley. The process used is the old "black ash," with stationary furnace. The capacity of the works is about 2 tons of sodium hydrate per day. The capacity of the furnace is $3\frac{1}{2}$ tons of sodium sulphate per day. Rescreened coal from the Rock Spring Mine is used and the limestone necessary is obtained near Laramie. The "black balls," formed of the fused soda, coal and lime, are broken up and washed in four lixiviating pans, and the liquor is then taken to two settling vats. Thence it is drawn to the "causticizer," which is a large circular tank in which are two perforated vessels containing caustic lime, around which the solution of sodium carbonate is agitated. After the causticising the liquor is passed through three long circular iron settlers. The clear liquor is then drawn to the "V-pan," where waste heat is used to aid the evaporation of the solution. The slightly concentrated liquor is then drawn to the "boat pan," which is set upon the reverberatory furnace. The evaporation is then continued as long as possible, and the now concentrated solution is then drawn to another room into the "finishing pot." This is a large cast-iron pot set directly over a furnace. Here all remaining traces of water are driven off at a low red heat. The hydrate at this stage is generally black and small quantities of niter are added to the fused mass to whiten it. The hydrate is then ladled into sheet-iron vessels and shipped. Some of the Laramie caustic soda has been used by the Denver Soap Company, which reports favorable results from its use. The works at Laramie are not well adapted to the most economical handling of the soda. Improvements are now being made by which the number of men employed will be greatly reduced and the composition of the "black balls" be made more uniform.

When the soda works were first begun it was supposed that the natural occurrence of the material as a sulphate, rendering unnecessary the reduction of the chloride to the form of a sulphate, would greatly decrease the ultimate cost of the caustic soda; but it was found that the very large quantity of water present in the soda as it comes from the lakes, more than offset, by the trouble and delay it cost in the furnaces, the gain in the natural form of the soda.

The Laramie works produced from July to January, 1885, about 30 tons of caustic soda. Defects in the plant have caused great delay and loss of some of the caustic soda, and it has been decided to close the works until alterations now being made can be completed. The lessee of the works states that good reports of the caustic soda have been made by users of it.

The "Donney" soda lakes are situated about 18 miles southwest of Laramie and are three in number covering, with the land included, approximately 520 acres. In one lake the deposit is 11 feet thick; in the others it is 5 to 6 feet. The soda from these lakes is similar to that from the Union Pacific lakes and there seems to be an underground connection between the two groups. In boring an artesian well near

These lakes to prospect the underlying strata, a brine was obtained which upon analysis showed—

Analysis of brine from near the Donney Lakes.

	Grains per gallon.	Per cent.
Sodium chloride	2002.0	2.86
Sodium sulphate.....	777.2	1.10

The large percentage of salt is very curious, as only traces of it are found in these lakes.

The soda deposits in Carbon County are situated in the Sweet Water valley, near Independence Rock, and are nearly 50 miles due north of Rawlins. These deposits contain both carbonate and sulphate of soda, and are generally known as the "Donney Lakes." The lakes are four in number, and vary from 6 to 2,000 acres in area, and are held by United States patents in the name of L. Dupont. There are five claims known as the "New York Soda Mine," 160 acres; the "Philadelphia," 80; the "Omaha," 20; the "Wilmington," 160, and the "Wilkesbarre," 20. The Omaha soda mine includes 20 acres, of which 5 are covered with carbonate and sulphate of soda, mixed with a little chloride of sodium and sand blown in from the surrounding soil. Several bore-holes were put down and show an average thickness of about 6 feet.

Amount of Na_2CO_3 contained in the samples.

No. 1, $3\frac{1}{2}$ feet from surface.....	per cent..	24.62
No. 2, surface.....	per cent..	41.55
No. 3, surface near shore.....	per cent..	32.42
No. 3, water.....	pounds per gallon..	1.33

A fused sample showed 52.23 per cent. of carbonate of soda. A fuller analysis of sample taken from the surface showed:

Analysis of surface soda from Carbon County, Wyo.

Moisture.....	9.01
Insoluble	2.61
Sulphate of soda.....	25.75
Chloride of sodium.....	2.13
Carbonate of soda.....	30.62
Bicarbonate of soda.....	30.09
	100.21

Another sample from near the surface contained 56.3 per cent of water:

Analysis of dry salt.

	Per cent.
Chloride of sodium	0.65
Sulphate of soda.....	59.29
Carbonate of soda.....	27.60
Insoluble matter.....	1.20

The variations and the proportions of carbonate and sulphate of soda are shown by the following table, the samples having been dried:

Samples.	NaCl.	Na_2SO_4 .	Na_2CO_3 .
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Five feet below surface	0.979	64.05	15.60
Do	0.32	65.08	16.70
Surface	0.81	17.02	80.60

The Wilkesbarre claim is about one mile west of the Omaha, and the soda is in solution. Samples of this solution showed by analysis:

	<i>Per cent.</i>
No. 1, Na_2CO_3 grains per gallon—	3,728 = 6.39
No. 2, Na_2CO_3 grains per gallon—	4,905 = 8.40

The Wilmington claim is located one-quarter of a mile west of the Wilkesbarre, and covers 160 acres. The soda here is also in solution. Its depth has never been determined. It has been sounded with a 40-foot rope without finding bottom in the center. A sample of this solution contained 2,343 grains per gallon (4.01 per cent.) A sample which had crystallized out by cold, when dried showed:

Chloride of sodium.....	1.83
Sulphate of soda.....	39.04
Carbonate of soda.....	59.00
Insoluble matter.....	9.23

The New York and Philadelphia are both upon one lake, which is solid, and is 4 miles west of the Wilmington. Two bore-holes have been put down in this lake. One, at a distance of 50 feet from the shore, showed 4 feet of soda; the other, at a distance of 230 feet from the shore, passed through 14 feet of solid soda without touching bottom. Three samples taken from this lake showed as follows:

	No. 1.	No. 2.	No. 3.
Chloride of sodium.....	1.83	2.04	2.52
Sulphate of soda.....	71.37	44.77	72.40
Carbonate of soda.....	3.10	5.00	5.10
Insoluble matter.....	22.82	47.50	19.03
	99.12	99.31	99.05

Fifteen miles from these soda deposits good limestone, containing 2 per cent of magnesia, occurs in the Seminoe mountains. Near the limestone is a good 8-foot vein of coal. A comparison of the analyses from the Donney and Union Pacific lakes and those of the Dupont lakes show how much greater the percentage of carbonate of soda in the latter is. The Sweet Water country is still out of the reach of transportation, and until a railway is built in this direction these soda deposits must remain undeveloped.

The Wyoming occurrences are typical sulphate deposits, and in many respects resemble those of Armenia, already described. Although they all contain more or less carbonate, yet, so far as we now know, it is not possible to extract the carbonate economically by natural crystallization processes. Under the most favorable circumstances the use of artificial heat is necessary, and, as stated above, the native sulphate, owing to the large proportion of water, has no advantage in point of cost and ease of working over the artificial. Careful and systematic study and experiment will doubtless, however, develop a good commercial method for the treatment of this material, since fuel can be easily obtained at a steadily decreasing cost, and transportation facilities are becoming greater.

Proceeding westwardly from the Wyoming deposits one finds numerous occurrences of salts more or less alkaline in character. Descriptions and analyses of many of these are given by King¹ and Russell;² but

¹ King: *Geol. Expl. 40th parallel*, vols. 1 and 2.

² Russell: *Geol. Hist. of Lake Lahontan* U. S. Geol. Survey, Mon. No. 11.

most of them are only thin efflorescences or incrustations, and, so far as we know, none have any commercial value until we reach

The soda lakes at Ragtown, Nevada.—These remarkable alkaline lakes or ponds are described at length by King in the work just cited,¹ also by Russell, Monograph, 11, pp. 73–80. From the latter report the following extracts are taken :

On the Carson desert, about 2 miles northeast of Ragtown, are two circular depressions that are partially filled with strongly alkaline waters and known as the Soda lakes or Ragtown Ponds. * * * The larger lake is 268.5 acres in area. * * * The rim in its highest part rises 80 feet above the surrounding desert, and is 165 feet higher than the surface of the lake which it incloses. The outer slope of the cone is gentle, and merges almost imperceptibly with the desert surface ; but the inner slope is abrupt, and at times approaches the perpendicular. A series of careful soundings gives 147 feet as the greatest depth of the lake. The total depth of the depression is therefore 312 feet, and its bottom is 232 feet lower than the general surface of the desert near at hand.

The walls encircling the lake exhibit well exposed sections of stratified lapilli mingled with an abundance of angular grains, kernels and masses of basalt, some of which are 2 and 3 feet in diameter, and scoriaceous, especially in the interior. * * * The form of the cones and the nature of the materials of which they are composed leave no doubt this is a crater ring, viz, a low cone of eruption containing a large crater. That the cones were not formed during a single eruption, but have a long and complicated history, and are perhaps sublacustrine in their origin, is shown by the alternation of ejected and sedimentary materials in the crater walls.

“The smaller lake,” according to Hague, “in most of its features, bears a close resemblance to the one just described and from which it is separated by a narrow ridge only an eighth of a mile wide. It has the same crater-like basin, but the banks are not more than 60 or 70 feet in height and the lake, even in spring, is scarcely more than one-fifth of a mile in diameter. There is no supply of fresh water from the surface, and at the time of our visit, in August, the water was much more dense than in the larger lake. Over a great part of the surface was found a thick incrustation of trona strong enough to bear up a man, under which is a greenish slime and occasional pools of water. One characteristic feature of the shore is the green and purplish tints of the moist sands, which, upon being dried, present the usual earthy colors.”

The trona from the small soda lake, upon being subjected to analysis yielded the following :²

Sulphate of soda.....	0. 99
Chloride of sodium.....	1. 10
Carbonate of soda.....	66. 27
Water and free carbonic acid.....	28. 83
Insoluble residue.....	2. 81
	100. 00

¹ Vol. 1, p. 510–513 ; vol. 2, p. 746–750.

² Hague: King's Rep. 40th Parallel, vol. 2, 1877, p. 749. Russell (op. cit., p. 73, note) says: “The smaller lake (in 1882) had been so changed by excavation and the construction of evaporating vats that its original form had been destroyed. Its surface is 20 feet higher than the larger lake and 65 feet below the general desert surface. The highest point on the crater rim is 80 feet above the bottom of the depression.”

Hague also says of these lakes (op. cit., p. 746): "they lie below the level of the plain, in which are probably ancient craters, and are not exposed until just before reaching the brink." King (op. cit., vol. 1, 512) considers "that during the period of the occupancy of this region by Lake Lahontan * * * these crater-like lakes were points of extremely powerful springs deriving their great activity from volcanic sources," and gives his observations at Mono Lake, to which we shall refer later.

Russell, on the other hand, says (p. 74):

The hypothesis that the craters were formed by the action of extremely powerful blastiferous springs, as advanced by King, would not account for the nature of the material forming the crater walls, nor the presence of the numerous volcanic bombs that depress the strata on which they rest. If the cavities owed their origin to rings of very great magnitude rising in the bottom of Lake Lahontan, it is evident that the outflowing waters would have cut channels of overflow when the lake evaporated to a horizon below the rim of unconsolidated material that surrounded them; but the crater walls are now continuous and unbroken by stream channels. On the other hand, had the springs become extinct before the evaporation of the lake, the cavities they formerly occupied would be buried beneath lake beds. This, as our observations show, is not the case, but both the inner and outer surfaces of the cones are free from lake sediments. The latest additions to the cones must have been of recent date. * * * There are no streams either tributary to or draining these lakes; their total water-supply, excepting the small amount derived from direct precipitation, is derived from subterranean sources. Around the immediate shores of the larger lake there are a number of fresh-water springs; the largest of these is situated on the northern border of the basin and issues from a small fault at an elevation of about 15 feet above the water surface. As the lake is 50 feet below the level of the Carson River at its nearest point, we may safely look to this stream as the probable source of the water-supply, which reaches the craters by percolation through the intervening marls and lapilli deposits. The bottom of the lake is a continuation of the slope of the inner walls of the crater, * * * is a fine black tenacious mud, giving a strong odor of sulphuretted hydrogen. When exposed to the air for some time this material loses its inky color, and shows itself to be of the same nature as the fine dust-like lapilli that form a large part of the crater walls. The organic matter impregnating these sediments is evidently derived from the millions of brine shrimp (*Artemia gracilis*) and the larvæ of black flies that swarm in the dense saline waters.

My own observations in the summer of 1887 were confined to the technical aspects of the manufacture of sodium carbonate as carried on here, and the short time at my disposal did not allow me to take more than a cursory view of the formation, but I have little doubt that Mr. Russell's conclusions are correct, since they are supported by what may be seen at both Mono and Owen's Lakes.

The details of the manufacture of soda at these lakes are of great interest, since, as they differ so greatly in composition, an entirely different method must be employed for each.

The water of the larger lake collected in 1867 was analyzed by O. D. Allen (King's Rep., vol. 2, p. 747), and two samples, collected in 1882 by Mr. Russell in the central portion of the lake at the respective depths of 1 foot and 100 feet, were examined by me. My results, given below,

agree very well, but differ from those of Allen mainly in that he reports the existence of sulphides, while I was unable to find any. If, as is very probable, Allen's sample was shipped to him in a keg, the presence of sulphides is easily accounted for by the reduction of sulphates by the action of the wooden vessel, since every sample of alkali water sent to this office in kegs has shown decomposition with resulting sulphuretted hydrogen, while the same material shipped in glass, as were Mr. Russell's waters, was free from it.

The variations in composition between the water at 1 foot and that at 100 feet may in part be due to the fact that the mother liquors of the soda works are run back into the lake. These mother liquors are poorer in carbonate and richer in chloride than the original water, and may in the course of years have changed the composition of the upper part of the lake.

The results are stated in grams per liter,¹ and the hypothetical combinations between the constituents are such as they may reasonably be expected to form. The columns of percentages show the relation of the constituents to each other, and will be found of practical value.

Specific gravity at 19.8° C.	No. 1 (1 foot).		No. 2 (100 feet).	
	1.0995.		1.0983.	
	Weight.	Per cent.	Weight.	Per cent.
Silica, SiO ₂	.304	.24	.310	.25
Magnesium, Mg.....	.270	.21	.270	.21
Potassium, K.....	2.520	1.95	2.670	2.13
Sodium, Na.....	45.840	35.53	44.270	35.23
Boric acid, B ₂ O ₃	.314	.24	.3.7	.26
Chlorine, Cl.....	45.690	35.41	44.270	35.23
Sulphuric acid, SO ₂	10.800	8.37	10.593	8.43
Oxygen, O.....	2.160	1.68	2.117	1.69
Carbonic acid, CO ₂	15.351	11.80	15.128	12.04
Oxygen, O.....	5.583	4.34	5.501	4.38
Hydrogen (in bicarbonates) H.....	.179	.14	.188	.15
	129.011	100.00	125.644	100.00

¹ The statement of results of analyses of such waters as so many grammes to the liter is preferable to the usual method of stating them as so many parts per thousand or per million. Any one handling such material necessarily measures his solutions by volume and his products by weight. The metrical system is used throughout as in every respect more practical for the manufacturer, being not only a decimal system, but also giving an instantaneous conversion from measure to weight, and vice versa, without the labor of calculation. As small variations are sometimes met with in the tables found in ordinary books, we give the following as the best for comparison:

A liter of pure water at 4°C = 1000 grammes = 1 kilo = 2.2046 lbs. = .264131 U. S. gallons, 1000 kilos = 1.1023 ton (2000 lbs.). 1 U. S. gallon = 3.786 liters.

1 meter = 39.3708 inches. 1000 liters = 1 cubic meter.

The specific gravity of a liquid is the weight of a liter in grams. Thus a liter of *Ragtown* water, specific gravity 1.0995, weighs 1099.5 grams and a cubic meter 1099.5 kilos.

Hypothetical combination.	No. 1.		No. 2.	
	Weight.	Per cent.	Weight.	Per cent.
Silica, SiO_2	.304	.24	.310	.25
Magnesium carbonate, MgCO_3	.945	.73	.945	.75
Potassium chloride, KCl	4.808	3.73	5.094	4.06
Sodium chloride, NaCl	71.521	55.44	68.957	54.88
Sodium sulphate, Na_2SO_4	19.170	14.86	18.800	14.96
Sodium, bi-borate (borax) $\text{Na}_2\text{B}_4\text{O}_7$..	.406	.31	.423	.34
Sodium carbonate, Na_2CO_3	16.868	13.08	15.484	12.32
Sodium bicarbonate, NaHCO_3	14.989	11.61	15.631	12.44
	129.011	100.00	125.644	100.00

The Ragtown Soda Works.—Mr. Russell's monograph contains an excellent map of the two lakes, drawn on so large a scale that the evaporating vats and their arrangements are clearly shown. He also gives many details of the manufacturing processes employed.

Two sets of works were in operation at the "Big Lake" in 1887, one belonging to Griswold & Epperson, the other to Smith & Allen. Both works use the same process and the evaporating vats are alike. Owing to the narrowness of the beach it was necessary to build the vats in the water, which was done by running out levees at right angles to the shore and connecting the ends of these by a main dike, thus forming rectangular compartments, which by use gradually became practically water-tight. Along the shore back of the vats runs a ditch, which is kept filled with lake water, and from this the vats are filled as needed.

Certain of the vats are used as "crystallizers," the rest as "evaporators." At the beginning of the season all are filled with lake water, and as this concentrates it is drawn from the evaporators into the crystallizers, so as to keep the latter at the proper depth—about 12 to 15 inches. As fast as this is done the evaporators are filled up with lake water from the ditch. In concentrating the brine gradually becomes a deep red (see page 95) and when it reaches 30° Baumé crystallization usually begins. From this time on, the crystallizers must be carefully watched lest the soda as it forms should be too much contaminated with sulphate or chloride. There is no simple means of detecting the formation of sulphate, but when common salt forms it crystallizes in minute glistening cubes upon the surface of the brine. A sudden lowering of the temperature generally has this effect, which must be remedied by drawing off a part of the mother liquor and supplying its place with concentrated brine from the evaporators or even with lake water. This drawing off is, of course, only necessary if the vat is already full, otherwise the concentrated brine or lake water is added directly to the vat in sufficient quantity to re-dissolve the NaCl .

The crystallization process is allowed to go on in this manner until the sheet of crystals at the bottom of the vat has grown thick enough

to be easily gathered or "lifted," say one-half inch to $1\frac{1}{2}$ inches. The mother liquor is then drawn off into the lake, and the crop lifted and stacked up to drain. As this soda is made during the summer it is known as "summer soda," and is the product of the Big Lake. This is the material called in King's report "trona," but is in reality "urao," as will be shown by the analysis on page 52. In the process of gathering the crystal sheet is broken up into cakes, which are a hard and compact aggregate of crystals sometimes well formed.

When the crop is drained it is heated in a furnace to remove the water of crystallization and the excess of carbonic acid, and is then sacked and shipped as "soda ash."

The furnace is a single hearth reverberatory, the hearth bed being made of iron plate. The fire gases pass over the charge to the end of the hearth, then through two side flues, one on each side, under the iron plate, back to the bridge wall, thence return through a center flue to the end of the hearth, where the stack is placed. The soda is dumped through an opening in the top of the arch onto the hearth, and is spread out evenly and heated for three hours, and then stirred from time to time until it is entirely dry. The furnacing as there practiced is a very simple operation, as the material parts with its water readily, and does not fuse, or even sinter, unless the heat is too high, and this is easily prevented by a little care in the stirring. In regular operation nine charges are worked off in a week; the fuel is sage-brush, gathered in the vicinity. Annual production about 450 tons, but this could easily be made much larger.

The operations at the Little Lake are conducted on an entirely different principle. The lake, as described in King's report, no longer exists, but the present appearance of the place is well shown in Russell's map. In the center of the depression there were at the time of my visit (1887) four large but shallow pits, besides a shallow pool somewhat larger, and filled with fresh water from the small springs which issue from the sides of the crater. Two of the pits are used as crystallizers and are supplied from the others, which contain a lye of about 12° to 13° Baumé. The lye is formed by the gradual solution of the "ledge" or deposit of crystallized sodium carbonate which exists in the bottom. No analysis of this ledge has so far as is known ever been made, and in consequence of the work which has been done it is difficult to obtain specimens. That material which was dug out for me had a close resemblance to dirty ice, although at one time it could be obtained in masses of considerable size and quite clean. Its appearance and the nature of its solution leave no doubt that it is a natural "crystal soda" or $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ in a comparatively pure condition.

The solution of this deposit, owing to the small amount of bicarbonate present, yields but little "summer soda." The concentration therefore continues, more lye being added from time to time until cold weather

sets in. Usually by January the lye is sufficiently concentrated and chilled, resulting in a copious crystallization of "winter soda" or $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, which is deposited on the thin layer of summer soda on the bottom of the vat.

When no more crystals appear to form, by which time the deposit is 10 or 12 inches thick, the crop is lifted and carefully stacked preparatory to the drying process, the most delicate part of the work. The $10\text{H}_2\text{O}$ salt contains 63 per cent. of water, and parts with most of it with great ease and rapidity, so that if heated to 33°C . (90°F .) it melts in its own water of crystallization and becomes a liquid. In drying the crop great care must therefore be exercised lest the material should become liquid and much of it be lost.

The crop is therefore kept in the stacks until the approach of warm weather, when it is broken up and spread in a layer two or three inches deep on the drying floors, which are covered with light sheds open at the sides. The material is turned over from time to time and the lumps broken up. When the drying is completed the product is a thoroughly effloresced white powder, in which the summer soda appears as small pieces of thin cakes. The annual product amounts to about 300 tons.

Before giving the analyses of the products of the two lakes, a few words of comparison between these two processes will aid much in giving a clear understanding of the meaning conveyed by the analytical figures.

The analysis of the water of the Big Lake has already been given. Though no analysis of the deposit of the Little Lake can be furnished, it is evident that it must give a solution much poorer in chloride and sulphate than the first locality. Let us see why this must be so.

When Hague visited these lakes in 1868 they had never been worked, and were therefore in their original condition. From the Little Lake he collected the material of which the analysis is given on page 46. On the shore of the Big Lake there were "large fields of dazzling white carbonate of soda," a sample of which was examined by O. D. Allen with the following results:

Water, H_2O	19.90
Insoluble residue.....	.80
Sulphuric acid, SO_3	.73
Chlorine, Cl	.98
Carbonic Acid, CO_2	36.86
Soda, Na_2O	40.55
	99.82
Deduct oxygen = Cl	.22
	99.60

The deduction of oxygen = Cl is made because the whole of the Na is calculated as oxide Na_2O , whereas that part combined with Cl is present as Na .

To compare these two analyses, let us calculate the hypothetical combination of this last analysis and place it side by side with the first one, in which the 28.83 per cent. of CO_2 and H_2O have been divided into the constituents, so that the full theoretical amount of Na_2CO_3 is supposed to be present. If the theoretical amount of NaHCO_3 be taken, the results will be found to vary very slightly.

	Big Lake.	Little Lake.
Insoluble matter.....	.80	2.81
Sodium sulphate, Na_2SO_4	1.29	.99
Sodium chloride, NaCl	1.61	1.10
Sodium carbonate, Na_2CO_3	45.05	44.25
Sodium bicarbonate, NaHCO_3 ..	34.66	34.90
Water, H_2O	16.19	15.95
	99.60	100.00

If we were to deduct the insoluble matter from each of these analyses and recalculate them we should find but little difference between the two samples, which will be referred to later in the section treating of urao. They evidently represent the first and purest crystallization of the "summer soda" from the two lakes.

At the Big Lake, however, the process must stop at the point where this crystallization is obtained, while at the Little Lake the process is allowed to go on and the "winter soda" is collected with the summer product. Russell procured samples of the "market soda" from each of these lakes, but neither of them seems to have been correctly taken, as the Little Lake soda contains too large a proportion of summer soda and the Big Lake material is the result of attempts, which naturally failed, to make winter soda at that place.

	Big Lake.	Little Lake.
	F. W. Taylor.	Chatard.
Silica, SiO_2	.449	.27
Iron and alumina, $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3$..	.011	.....
Calcium sulphate, CaSO_4	.038	.....
Magnesium sulphate, CaSO_4	.040	.....
Sodium chloride, NaCl	2.193	3.31
Sodium sulphate, Na_2SO_4	49.437	5.10
Sodium carbonate, Na_2CO_3	40.714	52.20
Sodium bicarbonate, NaHCO_3 .....	.....	25.05
Water, H_2O	7.118	14.16
	100.000	100.00

These two analyses are valuable for comparison in this connection, although in the first one the acid CO_2 of the NaHCO_3 was not determined,

g included in the H_2O which was evidently determined by differ-

The chilling of the solutions would not materially increase the solution of $NaCl$, but would greatly increase that of Na_2SO_4 , hence the solution of the Little Lake must contain much less of the latter than the other water, the analysis of which has been given. The combined product of the two lakes, as has been stated, is about 1,500 tons per annum. The Little Lake has nearly reached the limit of annual capacity, but the Big Lake might without great expense yield more. With proper working the two lakes should yield 1,500 tons per annum.

Mono Lake, Mono County, Cal.—A very extensive description of this lake is given by Mr. I. C. Russell in his article "Quaternary History of Mono Valley," in the Eighth Annual Report of the U. S. Geological Survey, and I can only repeat what I have elsewhere said "that this body of water, of a composition so favorable to utilization, is, for practical purposes, inaccessible and that the high altitude and consequent shortness of the evaporating season would, under any circumstances, render the success of any industry established there very doubtful. The composition of the water is, as shown by the annexed analysis, similar to that of Owen's Lake, which will be considered directly, but the same methods of economic treatment would apply to both, but owing to the reasons given above, there is little prospect that any extended use of the water of Mono Lake can ever be made.

The sample analyzed was collected by Mr. Russell in 1882 and was taken at the depth of one foot, on east side of lake. Specific gravity, 1.045 at 15.5° .

	In 1 liter.	Per cent.	Hypothetical composition.	Per cent.
SiO_2	.0700	.12	SiO_2	.0700 .13
K	.9614	1.79	$(Al_2Fe_2)O_3$..	.0030 .005
Na	19.6853	30.81	$CaCO_3$	.0500 .09
Ca	.0200	.037	$MgCO_3$	.1928 .36
Mg	.0551	.10	$Na_4B_4O_7$	.2071 .39
$(Al_2Fe_2)O_3$	.0030	.005	KCl	1.8365 3.44
SO_4	6.6720	12.480	$NaCl$	18.5033 34.60
CO_2	13.0903	25.61	Na_2SO_4	9.8690 18.45
B_2O_7	.1600	.30	Na_2CO_3	18.3556 34.33
Cl	12.1036	22.64	$NaHCO_3$	4.3856 8.20
H	.0522	.10		
	53.4729	100.00		53.4729 100.00

Bert Lake, Oregon.—This lake, situated in southeastern Oregon, may hereafter become of considerable importance, for though at present far from railroads and hence unavailable, yet with proper transpor-

¹ Chatard, Am. Jour. Sci., ser. 3, vol. 36, p. 148.

ation facilities the water could be utilized. The subjoined analysis of the water shows it to be the best suited for solar evaporation of all the lakes of the Great Basin, since, though not as concentrated as some others, the relation of the constituent salts is such that simple evaporation should give a very pure product. Summer Lake, not far distant, is supposed to have a similar composition.

Both lakes have been described by I. C. Russell¹ and by H. T. Biddle.² Mr. Russell's paper contains the following analysis of the waters of Abert Lake, which shows a very large percentage of potash (loc. cit. p. 454).

Sp. G., 1.02317.	Grams in liter.	Sp. G., 1.02317.	Grams in liter.
Silica in solution..	0.665	K ₂ CO ₃	10.961
NaCl	7.219	MgCO ₃	.006
KCl	8.455		27.357
K ₂ SO ₄	9.921		

From what is known of geological chemistry and the phenomena of rock decomposition, it is safe to say that no lake of this composition, or containing such a large proportion of potash, could be formed, but if such an occurrence should ever be discovered, the rock decompositions yielding such a solution must necessarily be entirely different from all those so far observed. It is due to my friend Dr. Taylor, who made the analysis in 1882, to state that when, some years later, his attention was called to this matter he at once recognized the unlikelihood of such a composition, but as the balance of his sample had not been preserved and he was unable to find the figures of his analyses, he could not rectify the error, which is probably only a simple arithmetical error of calculation in the estimation of the alkalies.

Mr. Biddle collected and examined a sample of the water of Abert Lake, and being unable to verify Dr. Taylor's results sent me the residue of his sample, which was examined with great care to settle the doubt. The sample was "collected by H. T. Biddle at middle of west side of lake, one foot below surface, 30-40 feet from shore, September, 1887." The total quantity at my disposal was about 200cm.³, an amount too small for any extended research, but sufficient for all practical purposes. For each determination, 25cm.³ = 25.7792 grams were taken.

Specific gravity, 1.03117 at 19.8°.

¹ Russell: Geological Reconnaissance in Southern Oregon, Fourth Annual Report U. S. Geological Survey, p. 435 et seq.

² Biddle, H. T.: Am. Jour. Sci., 3d ser. vol. 35, p. 475.

	Contents in 25 cm ³ .			In 1 liter.	Per cent.		Hypo- thetical compo- sition.	Per cent.
	A.	B.	Average.					
.....	.0063	.0058	.00580	.232	.59	SiO ₂	.232	.59
.....	.0133	.0136	.01345	.538	1.37	KCl	1.027	2.62
.....	.3674	.3671	.36725	14.690	37.51	NaCl	21.380	54.58
.....	.0148	.0146	.01470	.588	1.50	Na ₂ SO ₄	1.050	2.68
.....	.0030	.0029	.00295	.118	.30	Na ₂ CO ₃	10.611	27.09
.....	.1755	.1757	.17560	7.024	17.93	NaHCO ₃	4.872	12.44
.....	.0615	.0616	.06155	2.462	6.28			
.....	.3365	.3366	.33655	13.462	34.67			
onates				.058	.15			
.....				39.172	100.00		39.172	100.00

alysis shows, as would be expected, that the water of Abert is not differ materially from that of any other alkali lake so far. Its low percentage of sulphate is its greatest merit, since, shown under the section treating of Owen's Lake, it is of all ities the most difficult to remove and the most deleterious sent.

posits in the United States.—With the exception of Owen's foregoing are the only lakes which have a prospective value alkali industry, although there are many others which are but are too dilute for profitable working. There is, however, lass of alkali occurrences which may in time become avail- gh at present of minor importance. These are the so-called its left by the desiccation of shallow lakes formed in the wet the drainage of the surrounding country, but drying up more npletely during the summer, leaving an incrustation of salts onsiderable extent, though usually of no great thickness. region of the Black Rock Desert and adjacent parts lying Abert Lake and the line of the Central Pacific Railway there places which furnish such salts. The following analyses will ea of their composition:

ole portion of incrustation from near Black Rock Point, Black Rock Chatard. I. Russell, Monograph XI, U. S. Geological Survey, p. 231. n's River salts. O. D. Allen. King, 40th Parallel Survey, vol. 2, p. 791. in City salts, O. D. Allen. King, *ibid.*, p. 792.

	No. 1.	No. 2.	No. 3.
SiO ₂	2.18	*1.82	.....
KCl	1.39	†8.57	.....
NaCl	59.32	85.27	18.47
Na ₂ B ₄ O ₇ (borax)	1.00	.....	.....
Na ₂ SO ₄	27.05	1.75	27.55
Na ₂ CO ₃	9.06	2.59	52.10
	100.00	100.00	98.12

* Residue.

† Water.

The next five are also from King's 40th Parallel Exploration, and show the general character of the alkaline incrustations of eastern and central Nevada. In each case the amount of H_2O necessary to form $NaHCO_3$ has been added and the analysis calculated to 100 per cent. for comparison.

No. 4. Ruby Valley, Nevada (Woodward), vol. 1, p. 503.

No. 5. Valley of Deep Creek, Utah (Woodward), vol. 2, p. 474.

No. 6. Antelope Valley, Nevada (Woodward), vol. 2, p. 541.

No. 7. Humboldt Valley, Nevada (Woodward), vol. 2, p. 594.

No. 8. Brown Station, Humboldt Lake (Woodward), vol. 2, p. 744.

	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
K_2SO_4	2.79	4.68	1.88	.....	.....
Na_2SO_4	29.32	17.43	33.31	4.42	49.67
$NaCl$	2.11	38.01	24.51	7.24	20.88
Na_2CO_3	58.60	25.12	25.95	48.99	7.02
$NaHCO_3$	8.09	14.76	14.35	36.01	11.13
$Na_2B_4O_7$ .....	.....	.....	.....	3.34	11.30
	100.00	100.00	100.00	100.00	100.00

At many localities in western Nevada and in that portion of California east of the Sierra, incrustations of like character occur. Of these perhaps the most important are the soda lakes in Long Valley, California, lying southeastwardly of Mono Lake. The country is highly volcanic and the rocks are in many places much decomposed, having upon them efflorescences and incrustations. There are many warm springs, the waters of which flow into the lakes. These are several in number, connected together, with a drainage during the wet season into the headwaters of Owen's River. The shore shows in most places a salt crust around the margin, but in the hurried visit I paid this locality in the summer of 1886, I had no time to make a more particular examination, especially as the lakes are the deepest portions of extensive morasses, which in the winter are completely flooded. In the vicinity are large stretches of playa covered with thin sheets of alkaline salts, which are said to grow to the thickness of two or three inches on the approach of cold weather, when the material is gathered for the use of the mills at Bodie. A little to the north of the lakes is a so-called "hopper," a depression in the plain resembling on a small scale the Little Lake at Ragtown. The deepest part is filled with a small pool on which is a salt crust which covers the remainder of the bottom. The alkali from this place is also collected. Were there any facilities for transportation Long Valley might be made to yield a considerable amount of soda annually.

There are many other localities in this region, but further enumeration would be useless as the entire country is volcanic in its character,

and so far as there is any drainage the water flows into Owen's Lake.

Owen's Lake.—By far the most important natural source of soda is Owen's Lake, Inyo County, California, both on account of its magnitude and of the facilities for carrying on extensive operations.

It was visited by a party of the Wheeler Survey in 1875, and is described in the reports of Lieutenant Birnie and Dr. Oscar Loew, published in "Report of U. S. Geographical Surveys west of the 100th Meridian, 1876," pp. 130-135 and 189-190. Both in the summer of 1886 and of 1887 I spent some time at the lake, and as the Inyo Development Company has begun the manufacture of soda at Keeler, a small village on the shore of the lake at the terminus of the Carson and Colorado Railroad, every needed facility for observation and experiment was most courteously extended.

Loew (loc. cit.) states that the greatest length of the lake is 17 miles, its greatest width 9 miles, and greatest depth 51 feet. The total surface is given by him as nearly 110 square miles, and from his analysis of the water he calculates the total contents of the lake in sodium carbonate as 22,000,000 tons, and suggests the utilization of this great chemical treasure.

The lake lies between the Sierra Nevada on the west and the Inyo range on the east and has no outlet, the lowest point of the rim of the valley to the southward being, as I am informed, about 50 feet higher than the present level of the lake. On the western side several small streams from the Sierra make their way to the lake, but the greater portion of the water supply is furnished by the Owen's River which empties into the lake at its northern end. This, according to Loew, is a stream about 30 feet wide, 2 feet deep, with a velocity of about 5 miles an hour. It was my intention to collect accurate data concerning this river, as well as to get samples of the water taken at different points so as to determine the origin of the carbonate in the lake, but circumstances have prevented the prosecution of this part of the investigation.

As would be naturally expected the lake is somewhat higher in the spring than in the autumn, but its average depth suffers but little change, hence the evaporation from its surface seems to be at present about equal to the amount of water received from all sources. As the valley lies between two high ranges of mountains, and is open to the north and south, there is usually a good breeze through the greater part of the twenty-four hours, thus much increasing the evaporation which may safely be taken as about 5 feet in the year, though experiments give a larger result.

On the eastern side, the valley slopes gradually from the foot-hills to the lake. The shore is covered in most places with a strong growth of salt grass, though there are extensive sandy flats which are bare.

In the lake itself are large quantities of a sort of "algous or fungoid plant, floating in small globular masses of a whitish or yellowish green" (Loew). This collects in patches upon the water and becomes black with the clouds of "alkali flies" or ephydra which settle on it. In addition to the larva of these flies the water swarms with the artemia.

A carefully selected sample of the water of this lake taken September 17, 1886, gave me the following results. All the determinations were made in duplicate, the duplicates agreeing very closely. Specific gravity, 1.062 at 25°.

	In 1 liter.	Per cent.		Hypo- thetical compo- sition.	Per cent.
SiO ₂	.220	.28	SiO ₂	.220	.28
K	1.644	2.13	(Al ₂ Fe)O ₃	.038	.13
Na	28.500	36.96	(CaMg)CO ₃	.055	.63
Ca	.014	.02	Na ₂ B ₄ O ₇	.475	4.07
Mg	.005	.02	KCl	3.137	38.16
Fe ₂ O ₃	.014	.03	NaCl	29.415	14.38
Al ₂ O ₃	.024	.03	Na ₂ SO ₄	11.080	34.95
SO ₄	7.505	9.73	Na ₂ CO ₃	26.963	7.40
B ₂ O ₃	.367	.49	NaHCO ₃	5.715	
CO ₂	19.398	25.16			
Cl	19.344	25.09			
H	.063	.10			
	77.098	100.00		77.098	100.00

Owen's Lake Soda Works.—The works of the Inyo Development Company begun in the winter of 1885-'86, had so far progressed by the summer that a small amount of crude soda was produced. Lack of experience on the part of those in charge caused, however, many delays and disappointments, and it was not until the summer of 1887 that, under the management of Mr. Frank Gray, formerly of Ragtown, a fair start was made.

There are now nearly 15 acres of vats, mostly well made. The slope of the ground is such that the vats can be, in general, arranged in two lines so that the upper ones can be used as evaporators, the lower as crystallizers. By the method introduced by Mr. Gray the lye is allowed to concentrate in the crystallizers, more concentrated solution from the evaporators being added from time to time, till a sufficient quantity of the first crop is formed. This first crop is, however, comparatively soft and mushy owing to the small size of the crystals, so the mother liquor is drawn off; clear, well-settled lake water is added in sufficient quantity to redissolve the crystals and when this is done as completely as practicable, the vat is then filled up from the evaporators. By this means a new solution is obtained, containing a much smaller

proportion of chlorides and sulphates than the original lake water, and the crystals obtained from it are much larger and purer. The crystallization is allowed to go on, with additions from the evaporators until the cooler weather begins, when the soda is lifted.

The cake is then two or more inches in thickness, and if proper care be taken during its formation it should be quite clean and contain but little sulphate or chloride. An analysis of a sample of the crop of 1887, a good specimen but not better than could be made on a large scale with experience and judicious management, is given on page 76; "best specimen," while the "crude" is the undissolved first crop.

The process of furnacing this material so as to convert it into soda ash is very simple and easy, since the water and acid CO_2 is driven out at a temperature but little above 150°C . (300°F .), and no fusion takes place. If the material represented by the "best specimen" be thus heated it would give an ash containing 97.77 per cent. Na_2CO_3 , while the "crude" treated in the same manner would yield a 94 per cent. ash. When we consider that these favorable results have been obtained in the infancy of a process, without special skill or experience, it is not unreasonable to expect that, under proper technical management and with suitable arrangements and appliances, a product averaging 98 per cent. Na_2CO_3 can be made regularly and in large quantities, at this locality.

The calculation of Loew shows that this lake contains 22,000,000 tons of Na_2CO_3 , and if we make the moderate estimate that one-half of this amount can be extracted from it, and consider the natural advantages of climate and of the character of the shore which in many places is well adapted for the location of extensive works, there seems to be no reason why, in time, a large and flourishing industry should not develop there.

The small amount of the annual rain-fall and the very great annual evaporation resulting from a long season of very warm and dry weather are extremely favorable. No experiments determining the annual excess of evaporation over precipitation, have been made in this region but we have reason to think that it is not less than 7 feet per annum. The experiments now to be detailed show a much greater rate, but as they were carried on in small vessels fully exposed to the rays of the sun, the daily loss is, of course, far larger than would occur when an earth vat of large size is used for the purpose.

EXPERIMENTS ON THE EVAPORATION AND FRACTIONAL CRYSTALLIZATION OF THE WATER OF OWEN'S LAKE.

These investigations were made during the summer of 1886, for the purpose of obtaining information needed for the devising of manufacturing methods suitable for such waters.

Evaporation.—On September 6, noon, a granite-ware pot $7\frac{1}{2}$ inches

interior diameter, 6 inches deep, with straight sides, was filled $5\frac{3}{4}$ inches deep with lake water, specific gravity 1.057 at 18.3° (65° F.) The pot then contained $8\frac{1}{2}$ pints, the measurement of depth being made by sliding a rule along the side of the vessel until the lower end of the rule just touched the water. By having a thin strip of metal bent over the edge of the vessel the measurements can be made very closely. By using short hydrometers the specific gravity of the solution could be readily taken without disturbing the liquid.

Date.	Hour.	Depth to surface.	Loss.	Specific gravity.	Temperature.	Remarks.
		<i>Inches.</i>	<i>Inches.</i>			
Sept. 6	12 m.	$\frac{1}{2}$	.....	1.057	65° F. 18.3° C.	{ Filled pot; water filtered and clear.
Sept. 7	7.30 a. m.	$\frac{1}{2}$	$\frac{1}{2}$	1.07	60° 15.5°	
Sept. 7	5.30 p. m.	$1\frac{1}{2}$	$\frac{1}{2}$	.....	71° 21.7°	
Sept. 8	8.40 a. m.	$1\frac{1}{2}$	$\frac{1}{2}$	1.077	82° 27.8°	
Sept. 8	4.35 p. m.	2	$\frac{1}{2}$	1.082	75.5° 24°	
Sept. 9	7.45 a. m.	$2\frac{1}{2}$	$\frac{1}{2}$	1.090	85° 29.4°	{ Slightly whitish deposit at edge of liquid. Liquid slightly turbid.
Sept. 9	4.15 p. m.	$2\frac{1}{2}$	$\frac{1}{2}$	1.093		
Sept. 10	8.25 a. m.	$2\frac{1}{2}$	$\frac{1}{2}$	1.103	71° 21.7°	
Sept. 10	5.15 p. m.	3	$\frac{1}{2}$	1.110	85° 29.4°	{ A minute surface crystallization observed, probably CaCO_3 . Liquid more turbid.
Sept. 11	7.50 a. m.	$3\frac{3}{4}$	$\frac{3}{4}$	1.120	67.5° 15.8°	
Sept. 11	5.15 p. m.	$3\frac{1}{2}$	$\frac{5}{8}$	1.127	84° 28.9°	Hot wind from south.
Sept. 12	8.30 a. m.	$3\frac{1}{2}$	$\frac{1}{2}$	1.138	74° 23.3°	{ Liquid quite turbid. A thin granular precipitate on bottom and sides of vessel.

The concentrated solution was at this time transferred to a smaller granite-ware pot $6\frac{1}{2}$ inches wide, $5\frac{1}{2}$ inches deep. The surface of the solution was $2\frac{1}{4}$ inches below edge of pot, and, as the capacity of the vessel had been carefully measured for successive depths, the volume of the solution was $3\frac{1}{2}$ pints. The granular precipitate which adhered to the large pot consisted of CaCO_3 with a little Fe_2O_3 .

As the original solution measured $8\frac{1}{2}$ pints there was a loss of 5 pints, or 58.82 per cent., in bringing it to 1.138 (18° B.) at 23.3° (74° F.). When the liquid reaches 1.096 (13° B.) it begins to deposit its CaCO_3 , the maximum of deposit being at about 1.130–1.138 (17° – 18° B.). No increase of deposit was observed after the latter point was reached.

Date.	Hour.	Depth.	Loss.	Specific gravity.	Temperature.	Remark
		<i>Inches.</i>	<i>Inches.</i>			
Sept. 12	4.45 p. m.	2 $\frac{1}{8}$	$\frac{1}{8}$	1.150	80° 81.67°	
Sept. 13	7.35 a. m.	2 $\frac{1}{2}$	$\frac{1}{8}$	1.165	64° 17.78°	
Sept. 13	4.45 p. m.	3	$\frac{1}{8}$	1.175	84.5° 29.1°	
Sept. 14	8.20 a. m.	3 $\frac{1}{2}$	$\frac{1}{8}$	1.190	72° 22.2°	
Sept. 14	5.00 p. m.	3 $\frac{1}{2}$	$\frac{1}{8}$	1.215	86° 23.44°	
Sept. 15	9.00 a. m.	3 $\frac{1}{2}$	$\frac{1}{8}$	1.232	75° 24°	
Sept. 15	4.30 p. m.	3 $\frac{1}{2}$	$\frac{1}{8}$	1.250	87.5° 23.9°	
Sept. 16	8.45 a. m.	3 $\frac{1}{2}$	$\frac{1}{8}$	1.260	77° 25°	Incipient crystals
Sept. 16	4.35 p. m.	4	$\frac{1}{8}$	1.273	100° 37.78°	Crust formed.

At 8.45 a. m., the solution measured 1 $\frac{3}{4}$ pints. Hence concentration to the crystallizing point the liquid lost 6 $\frac{1}{2}$ per cent. of its bulk, or 5 volumes of Owen's Lake water as gravity and temperature above given are reduced to one volume crystallization begins. From these figures the proper relation between the evaporating and the crystallization surface is at once obtained; should be expected the daily loss diminishes as the solution concentrates; the total time of evaporation was nearly ten days, loss one-half inch per diem, maximum loss one inch, minimum one-half inch. Observations on earth vats, although roughly made, show an average evaporation of one-fourth inch in twenty-four hours under the same circumstances.

The rapid heating of the solution as soon as a crust formed on the surface is also worthy of notice.

Fractional crystallization.—The following experiments were made in order to determine the character and composition of the sucrose crystals obtained by the continued evaporation of a portion of Lake water, until the point is reached when the sun's heat is sufficient to drive off the water except with great slowness. In other words, to observe the gradations and extent of a practical crystallization.

September 3, 11.30 a. m.—Five quarts of filtered, partly evaporated lake water were put into each of two granite-ware pans, which were placed in the sun. The water had a specific gravity of 1.134. 10 quarts, so taken, being equivalent to 25 quarts of original water.

September 5, 8.30 a. m.—The solution in each pan had a small quantity of a fine granular precipitate, while a few small

crystals were floating on the surface. Solution pan No. 1, 1.282; No. 2, 1.270, both at $\frac{65^{\circ}}{13.3^{\circ}}$. Filled up pans with filtered water from vat, specific gravity 1.19 at $\frac{70^{\circ}}{24.4^{\circ}}$, adding to each 3 quarts, equivalent to $7\frac{1}{2}$ quarts original water. The total amount in the two pans was therefore equivalent to 40 quarts of lake water.

September 6, 7.30 a. m.—Both pans showed a large crop of crystals on bottom, while the liquid was turbid, with small crystals floating in it. Specific gravity of both solutions, 1.250 at $\frac{60^{\circ}}{15.5^{\circ}}$.

September 7.—Both pans had a stout crust with large deposit.

3.45 p. m.—Poured off mother liquor from both pans and drained crystals. The crop A1 weighed $1\frac{1}{2}$ pounds when dry. The combined mother liquors measured $5\frac{1}{2}$ quarts and had a specific gravity of 1.312 at $\frac{80.5^{\circ}}{27.9^{\circ}}$. This was put in one of the pans and allowed to evaporate.

September 8.—The solution was covered by a thin crust, with a considerable deposit of minute crystals on bottom.

September 9.—Poured off mother liquor from second crop, A2, which weighed 1 pound, and drained the crystals thoroughly. Mother liquor 1.312 at $\frac{77^{\circ}}{25^{\circ}}$.

September 10, 8.30 a. m.—Pan showed a considerable deposit of fine granular salts with thin crust on surface.

September 11, 8.30 a. m.—Drew off mother liquor and secured third crop, A3., which was highly saline to taste, and weighed three-fourths of a pound. The mother liquor had a specific gravity of 1.315 at $\frac{79.25^{\circ}}{26.25^{\circ}}$.

September 12, 5 p. m.—The solution was covered with thin, floating crusts, and its temperature was $\frac{103^{\circ}}{39.44^{\circ}}$, while the same thermometer exposed for five minutes to the direct rays of the sun showed barely $\frac{90^{\circ}}{32.2^{\circ}}$; another solution; B, of about 1.29 showed $\frac{91^{\circ}}{32.78^{\circ}}$.

The evaporation of this concentrated solution was very slow, so it was undisturbed until the 18th, when, as no further reduction in volume could be observed, the mother liquor was poured off, leaving the fourth crop A4. It had a specific gravity of 1.327 at $\frac{96.6^{\circ}}{35.75^{\circ}}$.

To observe the effect of cold at this stage, the vessel containing the solution was surrounded with ice. After four hours, at a temperature of $\frac{45^{\circ}}{7.23^{\circ}}$ a large deposit of a slushy material, looking like wet snow, was obtained. This crop, A5, was collected and placed in a pan to dry, but speedily melted in its water of crystallization, afterwards becoming a dry cake on the bottom of the pan. The mother liquor had a specific gravity of 1.300 at $\frac{57^{\circ}}{13.89^{\circ}}$, and was preserved for analysis.

The salts so obtained were analyzed with the following results, to which is prefixed an analysis of a sample of the crude soda made at the works in that year:

	Crop 1886.	A1.	A2.	A3.	A4.	A5.
Sp. gr. mother liquor.... {	1.280 (80° F.)	1.312 (80.5°)	1.312 (77°)	1.315 (79.25°)	1.327 (96.6°)	1.300 (57°)
Water at 120° C., H ₂ O	23.82	17.10	5.04	3.57	2.37	10.53
Water at red heat, H ₂ O	.33	.54	.41	.29	.24	.92
Insoluble matter.....	1.55	.078				
Organic matter	.18	.032				*1.14
Silica, SiO ₂	.14	.055	.055	.27	.05	.16
Alumina, Al ₂ O ₃	.01	.01	.015	.03	.01	.02
Lime, CaO	.01	.07	.02			
Magnesia, MgO	.01	.01	.009	.009		
Sulphuric acid, SO ₃	1.07	1.795	14.33	15.05	10.70	3.22
Chlorine, Cl	2.30	4.84	21.81	28.81	37.59	13.01
Carbonic acid, CO ₂	33.04	33.98	15.00	9.67	7.25	24.93
Soda, Na ₂ O	37.91	41.87	46.93	48.47	48.60	47.29
Potash, K ₂ O	.32	.68	.71	.72	.76	1.85
	100.75	101.15	104.33	106.64	108.66	103.07
Deduct O=Cl	.53	.78	4.91	6.49	8.75	2.93
	100.22	100.37	99.42	100.15	99.91	100.14

* Boric acid, B₂O₃.*Hypothetical combination.*

	Crop 1886.	A1.	A2.	A3.	A4.	A5.
H ₂ O	20.87	14.51	4.33	3.43	2.24	11.03
Insoluble	1.55	.078				
Organic	.18	.032				
SiO ₂	.14	.055			.05	.16
Al ₂ O ₃	.01	.01	.09	.06	.01	.02
(CaMg)CO ₃	.04	.14				
KCl	.51	1.07	1.12	1.14	1.21	2.93
NaCl	3.51	7.44	35.06	45.50	60.90	19.16
Na ₂ SO ₄	1.89	3.18	25.44	26.70	19.01	5.70
Na ₂ CO ₃	40.87	43.75	22.84	18.19	12.51	55.04
NaHCO ₃	30.65	30.12	10.53	4.06	3.88	4.09
Na ₂ B ₂ O ₄ (sodium borate) ..						2.01
	100.22	100.37	99.41	100.17	99.91	100.14

Another series of crystallizations was made at the same time (series B). In this, the first crop, B1 was collected when the mother liquor stood at a specific gravity of 1.285 at $\frac{80^{\circ}}{26.67^{\circ}}$; second crop, B2 with mother liquor of 1.325 at $\frac{81^{\circ}}{27.22^{\circ}}$; third crop, B3, mother liquor of 1.323 at $\frac{75^{\circ}}{23.39^{\circ}}$, and B4 under the same circumstances as A5.

	B1.	B2.	B3.	B4.
H ₂ O at 120° C.....	18.68	7.35	2.37	9.30
H ₂ O at red heat.....	.43	.41	.38	1.30
Insoluble	.17			
SiO ₂	.27	.04	.04	.21
Al ₂ O ₃	Trace.	.02		
CaO	.05			
MgO	.02			
SO ₂	1.49	12.44	13.55	3.50
Cl	3.70	22.63	35.50	14.74
CO ₂	34.72	15.31	6.10	23.25
Na ₂ O	40.87	40.30	49.61	47.62
K ₂ O	.65	.67	.73	2.21
B ₂ O ₃				* 1.10
	101.05	104.62	108.28	103.32
	.83	4.96	8.06	3.32
	100.22	99.66	100.28	100.00

<i>Specific gravity of mother liquor.</i>				
B1.....	1.285	(80°)		
B2.....	1.325	(81°)		
B3.....	1.323	(75°)		
B4.....	1.300	(57°)		

* By difference.

Hypothetical combination.

	B1.	B2.	B3.	B4.
H ₂ O	15.97	6.89	2.69	10.51
Insoluble	.17			
SiO ₂	.27	.04	.04	.21
Al ₂ O ₃	Trace.	.02		
(CaMg) CO ₃	.07			
KCl	1.02	1.00	1.15	3.51
NaCl	5.30	35.51	57.60	21.60
Na ₂ SO ₄	2.62	22.08	24.24	6.31
Na ₂ CO ₃	42.33	25.00	14.02	54.91
NaHCO ₃	32.47	9.12	.54	.87
Na ₂ B ₄ O ₇				2.08
	100.22	99.66	100.28	100.00

In B4 the boric acid, which was proved to exist in some quantity, was estimated by difference, as the process for its determination is tedious, and exact figures for this substance in cases like the present are of

the consequence. In the hypothetical combination the neutral borate $\text{Na}_2\text{B}_4\text{O}_7$ is given instead of borax or the acid borate $\text{Na}_2\text{B}_4\text{O}_7$. The latter can hardly be supposed to exist in such strongly alkaline solutions as those which produced A5 and B4. In the original water the acid borate is set down as probably existing, since a considerable excess of CO_2 is there present, which decomposes the neutral borate, forming $\text{Na}_2\text{B}_4\text{O}_7 + \text{Na}_2\text{CO}_3$.¹

DISCUSSION OF RESULTS.

In comparing these analyses let us first consider "crop 1886," A1 and . . . These are the first crops of a solar evaporation, and are the only ones of any technical importance, unless suitable processes can be devised for utilizing the mother liquors, which by simple evaporation yield products of too low grade for the market, where the value is fixed by the percentage of Na_2CO_3 in the ash and the proportion of other salts must not exceed certain limits.

Compared in this way, crop 1886 mother liquor 1.280 is the purest, . . . , mother liquor 1.285, comes next, and A1, mother liquor 1.312, is the next. It is evident, therefore, that if the first crop is to be used directly for making soda ash the concentration should not be allowed to run as far as 1.280, but, as, in such a case, the crop would be a comparatively small one, the advantages of a recrystallization are plainly indicated by comparison of the crop of 1886 with the "best" and "crude" of the crop of 1887. (See page 76.)

The rapid increase of SO_3 and Cl is shown by the two series. SO_3 reaches its maximum in A3 and B3 and then rapidly declines, while Cl is greatest in A4 and B3. NaHCO_3 is deposited in great part in the early stages of the crystallization; so that, when afterwards, most of the sulphates and chlorides are got rid of, the remaining solution contains a very large proportion of Na_2CO_3 , which separates when the solution is chilled.

The solar evaporation thus divides itself into three stages; first, the deposition of a comparatively pure compound of Na_2CO_3 and NaHCO_3 ; second, the formation of a product consisting in great part of sulphates and chlorides; and third, the production of a mother liquor requiring artificial heat for its further evaporation, but rich in Na_2CO_3 , and containing the major portion of the potash and boric acid.

Fractional crystallization of water of Mono Lake.—In this connection it will be interesting to compare the results of a similar series of crystallizations of some water from Mono Lake. This water had been concentrated by heating, and consequently most of the bicarbonate was reduced to normal carbonate; besides, the total quantity at disposal was so small that the results are not very reliable, but will show the general rule.

¹ Gmelin-Kraut: Anorg. Chem. II, 1. p. 157.

The concentrated water was about one-sixth of the original in volume, and had a specific gravity of 1.210. On being exposed to a dry atmosphere for quite a long period it began to deposit cubes of NaCl, and then a quantity of indefinite crystals (C1). These were collected, the mother liquor showing a specific gravity of 1.348. In time this solution gave a second crop C2, but did not vary in specific gravity. When, however, the third crop C3, had been obtained, the mother liquor showed a reduced specific gravity of 1.335. Continued evaporation yielded C4 mother liquor 1.361, and C5, mother liquor 1.381. The final evaporation to dryness gave C6. C5, when examined, was a mixture of cubes of NaCl resting on a layer of salts which, however, was too small in quantity to give accurate determinations, since, though carefully ground and mixed, concordant results could not be obtained. In such cases, where different salts crystallize together, concordant results can be looked for only when the sample, carefully weighed, is dissolved in water and portions of the solution weighed out for analysis. The figures obtained show that the composition of C5 lies between C4 and C6.

	C1.	C2.	C3.	C4.	C6.
Sp. gr. mother liquor ..	1.348	1.348	1.335	1.361	Dry.
H ₂ O	15.21	12.15	.60	4.59	11.37
SiO ₂	.07	.17	.16	trace.	.13
CaO	.03	.08	.03	.04	.01
MgO	.23	.22	.01	trace.	trace.
SO ₃	1.54	7.99	27.68	9.14	3.75
Cl	11.97	13.29	18.40	37.20	26.87
CO ₂	29.91	24.24	8.15	7.97	14.24
Na ₂ O	43.92	44.45	48.39	49.92	39.93
K ₂ O	.43	.43	.30	.45	9.60
	102.41	103.02	103.92	108.41	105.90
O=Cl	2.69	3.00	4.14	8.38	6.05
	99.72	100.02	99.78	100.03	99.85

Hypothetical combination.

	C1.	C2.	C3.	C4.	C6.
H ₂ O	12.28	10.98	.69	4.18	11.31
SiO ₂	.07	.17	.16	.....	.13
CaCO ₃	.05	.14	.05	.07	.02
MgCO ₃	.48	.46	.02	.....	.....
KCl	.69	.69	.47	.71	15.20
NaCl	19.18	21.34	29.96	60.75	32.36
Na ₂ SO ₄	2.73	14.18	49.13	16.22	6.65
Na ₂ CO ₃	36.87	41.07	18.27	14.22	33.69
NaHCO ₃	27.37	10.99	1.03	3.88	.49
	99.72	100.02	99.78	100.03	99.85

The comparison of series C with A and B illustrates still further the rule of deposition for each of the constituent salts. In addition we

while the percentage of chlorides in C1 is much greater than others, the amount of sulphates varies very slightly, though this may give us important hints, as it may have an especial bearing on the separation of the carbonates.

relation of Na_2CO_3 and NaHCO_3 is brought out by comparing percentages of the two salts with their molecular weights, $=106$, $\text{NaHCO}_3=84$, which gives us the following results:

	Per cent. Cl.	Per cent. SO_4 .	Per cent. NaHCO_3 ; per cent. Na_2CO_3 .
Crop 1886	2.36	1.07	30.65 : 40.87 :: 84 : 112
A1	4.84	1.79	30.12 : 43.75 :: 84 : 122
B1	3.70	1.49	32.47 : 42.33 :: 84 : 109.5
C1	11.97	1.54	27.37 : 36.87 :: 84 : 113.1

true molecular proportion would be 84 : 106, so that in each case an excess of Na_2CO_3 , the excess being greatest in A1 where the age of SO_4 , 1.79, is the largest. Strictly speaking, only A1 and B1 are really comparable, having been obtained under like condition, Crop 1886 was the product of a large mass of liquid, and the C1 from another locality had been boiled.

As shown by the specific gravity of the mother liquor, is the product of a higher degree of concentration than B1, and is less pure, which, as stated, seems to fix the limit of production of a first crop, for Lake water, at the point where the mother liquor has reached a specific gravity of 1.280, or even something less, since above this point the percentages of sulphates and chlorides rapidly increase without compensating increase of carbonates.

We are now prepared to study the nature of this combination of Na_2CO_3 and NaHCO_3 , on which such stress is laid, for reasons that will be given in the following discussion:

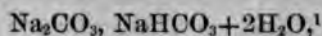
URAO.

Urato from Venezuela.—The occurrence in Venezuela of this native alkali has already been described on page 40, and on page 41, it was stated that this material is found in many places, is of great importance in the technology of natural soda, and would be treated in a separate section. Referring to page 41 for Boussingault's analysis of this salt, and repeating the results there given, we have:

Found.		Hypoth. comp.	
Na_2O	41.22	Na_2CO_3	46.98
CO_2	39.00	NaHCO_3	37.24
H_2O	18.80	H_2O	14.80
Impurities	.98	Impurities	.98
	100.00		100.00

The impurities are insoluble matter with chlorides and sulphates, all of which can be deducted when we desire to calculate the formula of the compound as these salts are under the circumstances anhydrous (see page 29), hence merely diminish the percentage of urao in the original material.

The formula already given for urao is



and if we deduct the impurities from Boussingault's analysis and recalculate the residue to 100 per cent. and likewise calculate the theoretical percentages for the above formula, we shall have

	Impurities deducted.	Theoretical. $\text{Na}_2\text{CO}_3, \text{NaHCO}_3 + 2\text{H}_2\text{O}.$	Difference.
Na_2O	41.63	41.15	+ .48
CO_2	39.38	38.94	+ .44
H_2O	18.99	19.91	— .92
	100.00	100.00	

Theoretical composition.

Na_2CO_3	47.44	46.90	+ .54
NaHCO_3	37.61	37.17	+ .44
$2\text{H}_2\text{O}$	14.95	15.93	— .98
	100.00	100.00	

Again, if we take the proportion between the Na_2CO_3 and the NaHCO_3 we have

$$\text{Na}_2\text{CO}_3 : \text{NaHCO}_3 :: 106 : 84 :: 47.44 : 37.50,$$

while the amount of NaHCO_3 found is 37.61, a difference of only 0.11 per cent. Hence Boussingault's urao is an almost theoretically pure salt, showing only a small loss of water and a trifling increase of NaHCO_3 .

Native urao from Egypt.—The analysis of Egyptian soda by Remy, given on page 39, if calculated in the same manner, shows a remarkable agreement with the foregoing. In his original paper, Remy gives as found SiO_2 , 0.144; CaO , 0.078; CO_2 , 32.160; SO_3 , 1.210, and Cl , 4.95 per cent., hence by reducing his analysis, as given, to its constituents we have

¹ Laurent: Ann. de Chimie, series 3, vol. 36, p. 348,

	Recalculated.		Hypothetical composition.
Insoluble	4.106	Insoluble	4.106
SiO ₂	.144	SiO ₂	.144
SO ₃	1.210	CaCO ₃	.20
Cl	4.950	NaCl	8.160
CO ₂	32.160	Na ₂ SO ₄	2.148
CaO	.078	Na ₂ CO ₃	38.45
Na ₂ O	39.080	NaHCO ₃	30.70
H ₂ O	19.669	H ₂ O	16.38
	101.397		
O = Cl	1.110		
	100.287		100.288

If now we deduct from the last column the 14.758 of impurities we shall get column *a*; if we recalculate to 100.00, column *b*; while if we figure the theoretical proportions of NaHCO₃ and H₂O required for the 44.95 per cent. of Na₂CO₃ in *b*, we obtain column *c*, and consequently the differences.

	<i>a</i>	<i>b</i>	<i>c</i>	Difference.
Na ₂ CO ₃	38.45	44.95	44.95	0.00
NaHCO ₃	30.70	35.90	35.62	+ .28
H ₂ O	16.38	19.15	15.27	+3.88
	85.53	100.00		

True character of trona, or the native sesquicarbonate.—From this it appears that Remy's trona, after deducting the impurities, is urao with a very slight excess of NaHCO₃, but 3.88 per cent. excess of H₂O. Whether or not the presence of this excess of water is to be ascribed to the Na₂SO₄, will become clearer as we go on.

Klaproth¹ in 1802 published the following analysis of a natural soda from near Fezzan in the Desert of Sahara:

	As published.	Impurities deducted.		Hypothetical composition.
Na ₂ O	37.00	37.95	Na ₂ CO ₃	35.88
CO ₂	38.00	38.97	NaHCO ₃	45.96
H ₂ O	22.50	23.08	H ₂ O	18.16
Na ₂ SO ₄	2.50			
	100.00	100.00		100.00

To this mineral the name trona has been given and it is considered as a native sesquicarbonate of sodium. As previously stated (page 35)

¹ Klaproth: Beiträge zur Chem. Kenntniss d. Mineralkörper, III, 1802, p. 83. Also see Dana's *Mineralogy*, article Trona.

"sesquicarbonate" is the name given to a supposed compound of Na_2CO_3 and NaHCO_3 in the proportion of one molecule of Na_2CO_3 to two of NaHCO_3 , with the addition of water. As by the dualistic formula formerly in use sodium monocarbonate was written NaO, CO_2 , and the bicarbonate $\text{NaO}, \text{HO}, 2\text{CO}_2$, the formula of the compound was written $2 \text{NaO}, 3 \text{CO}_2$ whence its name, the HO being omitted, not being considered an essential constituent. The formula of the theoretical sesquicarbonate is $\text{Na}_2\text{CO}_3, 2 \text{NaHCO}_3 + 3 \text{H}_2\text{O}$, which gives us the following percentages with which Klaproth's results are compared:

	Theoretical.	Klaproth.	Difference.
Na_2CO_3	32.32	35.88	+3.56
2NaHCO_3	51.22	45.96	-5.26
$3\text{H}_2\text{O}$	16.46	18.16	+1.70
	100.00	100.00	.....

These differences are too great to be considered as slight variations from a theoretical formula, such as are shown by Boussingault's mineral. If Klaproth's trona be compared with a theoretical urao the differences are still larger being $-11.02 \text{ Na}_2\text{CO}_3$, $+8.79 \text{ NaHCO}_3$ and $+2.23 \text{ H}_2\text{O}$, hence we see that we have here a mixture to which neither formula can be assigned.

Joffre¹ analyzed a trona stated to have come from the same locality and supposed to be the same as Klaproth's. He describes the mineral thus:

Incrustations of about 2 to 3 centimeters in thickness. It is in masses which are crystalline and perfectly white, except the lower part which is colored by a trace of oxide of iron.

After giving the figures of the analysis below, he says:

The first three numbers correspond to sesquicarbonate of soda, contaminated with a little carbonate of soda * * * should be included in the mineral species named urao. The presence of carbonate of lime and of chloride of sodium may give confirmation to the views of M. Berthollet concerning the origin of natural soda, which he ascribes to the reaction of these two substances upon each other.

	Joffre.	Impuri- ties de- ducted.		Hypo- thetical compo- sition.	Theoretical sesquicar- bonate.	Differ- ence.
Na_2O	39.41	40.01	Na_2CO_3	40.08	32.32	+7.76
CO_2	39.58	40.18	NaHCO_3	44.93	51.22	-6.29
H_2O	19.52	19.81	H_2O	14.99	16.46	-1.47
Sand.....	.53					
Fe_2O_3	.01					
CaCO_3	.05					
NaCl	.46					
Na_2SO_4	.44					
	100.00	100.00		100.00	100.00	.....

¹ Joffre: Bull. Société Chimique, vol 12, p. 102.

differences are, therefore, still greater than in Klaproth's trona, in fact, as far as is known, the only analyses of natural soda which are a composition at all near to true sesquicarbonate are those of

Popp's specimens came from Egypt, and are described as "distinctly saline salt crusts almost an inch thick," No. 1 was "an aggregate of small, transparent prismatic crystals, the prisms being clearly distinguishable."

	No. 1.	No. 2.	No. 3.
Insoluble	1.65	1.35	.40
CaO	.55	trace.	.....
SO ₃	1.65	13.53	37.56
Cl	5.11	20.25	1.58
CO ₂	33.15	16.55	13.50
Na ₂ O	36.34	43.68	43.10
H ₂ O	22.50	8.87	4.05
	100.95	104.23	100.19
Deduct O=Cl.....	1.15	4.56	.35
	99.80	99.67	99.84

Hypothetical composition.

	No. 1.	No. 2.	No. 3.
Insoluble	1.65	1.35	.40
Na ₂ SO ₄	2.93	24.01	66.67
NaCl	8.42	33.38	2.61
CaCO ₃	.99	.....	.....
Na ₂ CO ₃	25.81	13.40	10.60
NaHCO ₃	42.00	20.93	17.37
H ₂ O	18.00	6.60	2.19
	99.80	99.67	99.84

acting impurities as before and recalculating, we have,

	No. 1.	No. 2.	No. 3.
Na ₂ CO ₃	30.08	32.74	35.15
NaHCO ₃	48.94	51.13	57.59
H ₂ O	20.98	16.13	7.26
	100.00	100.00	100.00

In the composition of No. 1, Popp deduced the formula Na₂CO₃, 2 H₂O + 4 H₂O; No. 2 is close to Na₂CO₃, 2NaHCO₃ + 3 H₂O, while No. 3 approximates Na₂CO₃, 2NaHCO₃ + H₂O. The theoretical percentages

¹ Popp: Ann der Chemie u. Pharm., vol. 155, p. 348.

of these degrees of hydration and the differences from the respective analyses are as follows:

	4 H ₂ O.	Difference No. 1.	3 H ₂ O.	Difference No. 2.	1 H ₂ O.	Difference No. 3.
Na ₂ CO ₃	30.64	— .56	32.32	+ .42	36.30	— 1.15
NaHCO ₃	48.55	+ .39	51.22	— .09	57.54	+ .65
H ₂ O	20.81	+ .17	16.46	— .33	6.16	+ 1.10
	100.00	.....	100.00	.....	100.00	.....

These results are very remarkable and would appear to settle affirmatively the existence of true sesquicarbonate in nature, but we shall have occasion to refer to them later and give reasons for further doubt. The analysis of the incrustation from Brown's Station, Nev., given on page 56, may be disregarded in this connection, as the existence of the sesquicarbonate appears to have been assumed and one of the determinations obtained "by difference."

Artificial production of sesquicarbonate.—The artificial production of sesquicarbonate has been claimed by both Winkler and Hermann.

Winkler,¹ by dissolving 100 parts Na₂CO₃ and 152 parts NaHCO₃ in 1,920 parts of water and carefully adding 1,920 parts of 80 per cent. alcohol, so that the two liquids did not mix, obtained, after the lapse of several days, fine, transparent, non-efflorescent, acicular crystals. These adhered to the sides of the vessel and with them were crystals of hydrated monocarbonate and bicarbonate, the latter principally on the bottom. His analysis of the acicular crystals is given below.

Hermann² mixed thoroughly Na₂CO₃, 10 H₂O and NaHCO₃ in the proportion of 1 : 2, melted the mixture in the water of crystallization, and allowed the cold mass to remain in damp air for some weeks. At the end of that time the mass had become crystalline and its cavities were lined with crystals of sesquicarbonate, which he analyzed.

Both Winkler and Hermann give as the formula of the salt, 2 Na₂O, 3 CO₂ + 3 H₂O or Na₂CO₃, 2 NaHCO₃ + 2 H₂O, as is shown by the analyses.

	Molecular weight.	Theoretical per cent.	Winkler.	Hermann.
2 Na ₂ O.....	124	40.00	41.13	40.00
3 CO ₂	132	42.58	43.30	43.06
3 H ₂ O.....	54	17.42	15.57	16.94
	310	100.00	100.00	100.00

¹ Buchner's Repert. f. Pharm., vol. 48, p. 215.

² Journ. f. prakt. Chem., vol. 26, p. 312.

Hypothetical composition.

	Molecular weight.	Theoretical.	Winkler.	Difference.	Hermann.	Difference.
Na_2CO_3	100	34.20	36.33	+2.13	33.02	-1.18
2 NaHCO_3	168	54.19	53.87	-.32	56.04	+1.85
2 H_2O	36	11.01	9.80	-1.81	10.94	-.67
	310	100.00	100.00		100.00	

By following the directions given by Winkler small needles, such as he describes, were obtained; from these the material for analyses was selected with great care and appeared to be free from the other salts which had crystallized simultaneously. As the latter are sodium bicarbonate, and hydrated monocarbonate, the separation must be carefully made, else results may be obtained showing great variety in the proportions of the two. The amount of salt thus secured was small, but sufficient for the following duplicate analyses :

	a	b		a	b	Average.
H_2O	19.19	19.31	H_2O	14.64	14.75	14.69
CO_2	40.01	40.01	Na_2CO_3	42.72	42.67	42.70
Na_2O	40.60	40.67	NaHCO_3	42.53	42.57	42.55
	99.89	99.99		99.89	99.99	99.94

These results do not agree with those of Winkler nor with any of the salts described by Popp. Moreover, no simple theoretical formula can be assigned to the combination, and we have either a sesquicarbonate plus an excess of Na_2CO_3 , or what is more probable, urao plus an excess of NaHCO_3 .

The following table is a comparison of the foregoing analyses. As the proportion of water present varies for each sample, the percentage of Na_2CO_3 , 2 NaHCO_3 , or as it may be called "anhydrous sesquicarbonate," is calculated for each, and the excess, whether of monocarbonate or bicarbonate, thus shown.

	Na_2CO_3 , 2 NaHCO_3	Excess.
	Per cent.	Per cent.
Remy	62.42	18.43 Na_2CO_3
Joffre	73.28	11.73 Na_2CO_3
Klaproth	74.96	6.88 Na_2CO_3
Popp, No. 1	77.75	1.27 NaHCO_3
Popp, No. 2	83.39	.48 Na_2CO_3
Popp, No. 3	90.86	1.88 NaHCO_3
Hermann	85.35	3.72 NaHCO_3
Winkler	87.86	2.34 Na_2CO_3
Chatard	69.40	15.85 Na_2CO_3

The other analyses of natural soda which are known show still larger excesses of Na_2CO_3 than these. So far, therefore, the evidence in favor of the existence of sesquicarbonate is very unsatisfactory and must remain so until some one has succeeded in producing it by crystallization from aqueous solution by simple evaporation. My own experiments on the artificial formation of urao¹ appear to demonstrate the non-existence of the salt.

In addition to the analyses already given, we have Laugier's² examination of a Barbary soda, Pfeiffer's³ analysis of an East Indian soda, and Wallace's⁴ of several samples of soda from the Loonar Lake.

Wallace calls especial attention to the proportion of CO_2 to Na_2O as shown by his work, and remarks that although the text-books generally state that the trona from Egypt and other localities consisted of sodium sesquicarbonate, yet the analyses show that the sesquicarbonate and the neutral carbonate are associated in nearly equal proportions, and it appears likewise that under the circumstances in which the deposits were made, a compound of soda was formed that contains nearly four equivalents of soda to five of carbonic acid. In no case had he found the Na_2O and the CO_2 to be present in the proportions necessary to form either the neutral carbonate or the sesquicarbonate, and it is his opinion that lack of uniformity in stating the results of analysis was the cause of the error.

Tabulating the results of these analyses we have,

	Urao.	Excess Na_2CO_3 .	Urao.	Excess.
Allen, Big Lake, Ragtown (p. 52).....	78.39	1.32	100	1.68
Allen, Little Lake, Ragtown (p. 52).....	78.98	.17	100	.21
Chatard, Little Lake, Ragtown (p. 52).....	56.66	20.59	100	30.34
Woodward, Ruby Valley (p. 56).....	18.30	48.48	100	264.92
Woodward, Deep Creek (p. 56).....	33.38	6.50	100	19.47
Woodward, Antelope Valley (p. 56).....	32.46	7.84	100	24.12
Woodward, Humboldt Valley (p. 56).....	81.45	4.55	100	5.58
Pfeiffer.....	6.33	30.25	100	478.00
Laugier.....	52.48	25.48	100	48.55
Wallace, Dulla Khar.....	75.52	12.13	100	16.06
Wallace, Nummuck Dulla.....	5.54	2.34	100	42.24
Wallace, Papree.....	38.49	8.53	100	22.16
Wallace, Bhooskee.....	23.11	8.38	100	36.26

It is evident from the above that while, in each case, there is an excess of the neutral carbonate, the amount of this excess bears no general relation to the amount of urao or of sesquicarbonate present, and we must consider natural soda either as an indefinite mixture of

¹ Pp. 78 et seq.

² Laugier: Dingler's Polyt. Jour., vol. 18, p. 482.

³ Pfeiffer: Journ. f. prakt. Chemie, vol. 61, p. 439.

⁴ Wallace: Chem. News, vol. xxvii, p. 203.

the neutral carbonate and the bicarbonate or as a certain definite compound of these two salts, having the composition either of urao $\text{Na}_2\text{CO}_3, \text{NaHCO}_3$ or of sesquicarbonate $(\text{Na}_2\text{CO}_3, 2\text{NaHCO}_3)$ generally intermixed with an excess of one or the other of the two constituents.

No other combinations of these two substances have, up to the present time, been claimed to exist; the evidence for the sesquicarbonate has been given, and it remains to consider the proof of the existence of urao, not only as an occasionally occurring mineral, but also *the sole natural combination of the two carbonates*.

Urao from Owen's Lake.—We have already discussed Bonssingault's analysis of the original urao, and showed that this gave percentages remarkably close to the theoretical for the formula



and on page 59 reference was made to certain salts from Owen's Lake which are now to be considered.

The "best specimen," as there stated, is the result of the spontaneous vaporation of the water of the lake, for although the crystallization occurred in an artificial ground vat and the first crop was redissolved in lake water, yet nothing was added to the water, and solar heat only was the evaporating agent. Hence such a product is purely natural in its character, and must be considered as a "mineral," and not as an artificial substance.

The piece examined was one of several broken from a large fragment of the crystal sheet covering the bottom of the vat. It was a mass about two inches thick, the upper portion of which was well crystallized and translucent; the intermediate part, an interlamination of thin translucent crystallized sheets and of fine granular crystalline white material; the bottom of the specimen is a layer similar to the upper part, but thinner, the crystals being much smaller.

The analysis marked "best specimen" was made from the upper portion, which presented a columnar radiated structure, the crystals being so grown together that the terminations alone were visible and these so combined together that each combination had a curved ridge-like termination or cockscomb form. The specific gravity of the material was 2.1473 taken in benzol at 21.7°C . The "crude" is the fine granular material from the central part of the specimen, and is the undissolved residue of the first crop.

The "twig" urao was formed on a branching grass root which happened to be suspended in the water of a small natural lagoon on the east side of the lake. It has the form of a stout twig or of a branching coral, each of the branches forming a cylinder, a section of which shows the radiated structure, while the surface of the cylinder is rough, the curved edges of the crystal aggregates giving a lenticular appearance. The color is brownish, and one side of the specimen shows crystals of NaCl and much sand, as the evaporation of the water finally left it lying on the mud of the bottom.

The "lagune" specimen is from another small lagune near by, and consists of a thin sheet, the surfaces of which are rough like the preceding specimen. Color pink, due to organic matter. (See p. 95).

"Beach vat." This was formed in a vat dug in the beach and allowed to fill by seepage from the surrounding soil. Analyses of this seepage water will be found on page 94.

	Best specimen.			Average.
Insoluble (inorganic)				.02
Cl	.195	.191		.193
SO ₃	.707	.697		.702
CO ₂	38.18	38.11	38.10	38.13
Na ₂ O	40.98	41.01		40.995
H ₂ O	20.12	20.09	20.00	20.07
				100.110
Deduct O=Cl				.04
				100.07

	Crude.	Twig.	Lagune.	Beach vat.
Insoluble (inorganic) ..	.22	2.92	.40	4.10
Insoluble (organic)		.14	.12	.27
SiO ₂	.10	.05	.09	.04
Cl	1.57	2.73	.21	1.83
SO ₃	.79	.76	.63	.84
CO ₂	37.60	35.24	37.50	35.10
Na ₂ O	41.26	40.22	40.08	39.36
CaO			.06	
K ₂ O			trace	
MgO			.02	
H ₂ O	19.62	18.31	19.94	18.58
	100.56	100.37	99.05	100.12
O=Cl	.35	.61	.05	.41
	100.21	99.76	99.10	99.71

Hypothetical composition.

	Best specimen.	Crude.	Twig.	Lagune.	Beach vat.
Insoluble	.02	.22	3.06	.52	4.37
SiO ₂		.10	.05	.09	.04
CaCO ₃				.10	
MgCO ₃				.04	
NaCl	.32	2.58	4.50	.34	3.01
Na ₂ SO ₄	1.25	1.39	1.35	1.12	1.49
Na ₂ CO ₃	45.86	45.28	42.46	48.73	42.36
NaHCO ₃	36.46	34.74	33.63	31.49	33.44
H ₂ O	16.16	15.90	14.71	16.57	15.00
	100.07	100.21	99.76	99.00	99.71

Deducting NaCl and other impurities, as before, and recalculating to 100 per cent., we have—

	Best.	Crude.	Twig.	Lagune.	Beach vat.
Na ₂ CO ₃	46.57	47.20	46.76	50.35	46.65
NaHCO ₃	37.03	36.22	37.04	32.53	36.83
H ₂ O	16.40	16.58	16.20	17.12	16.52
	100.00	100.00	100.00	100.00	100.00

Finally, if we compare these new percentages with the theoretical figures for urao, already given, we shall find the following differences:

	Theo- retical.	Best.	Crude.	Twig.	Lagune.	Beach vat.
Na ₂ CO ₃	46.90	— .33	+ .30	— .14	+3.45	— .25
NaHCO ₃	37.17	— .14	— .95	— .13	—4.64	— .34
H ₂ O	15.93	+ .47	+ .65	+ .27	+1.19	+ .59

These small differences show that each of the samples is urao. In each case there is a varying amount of NaCl, Na₂SO₄, and other impurities to be deducted, but when this is done, the residue in four out of the five samples has a very close agreement with the formula of the mineral. In the case of the "lagune" the differences are quite large, but as the local circumstances attending the production of each specimen are well known, the explanation is simple.

The "best specimen," although obtained like the others by the spontaneous evaporation of the natural water, is, in effect, a recrystallization occurring in a shallow basin of no great extent. The process was slow, the insoluble impurities had time to settle, and the product was gathered as soon as a tendency to deposit NaCl was observed. That this was successfully done is shown by the analysis, but the percentage of Na₂SO₄ is not materially different from that of the other specimens made under less favorable circumstances. That this is to be expected follows from what we know of the relative solubility of the different salts. The solubility of NaCl is but little affected by changes of temperature, which have great influence on that of the sulphate and carbonates. The sulphate is not only more soluble than urao, but is also present in much smaller proportion in this water, hence it is not deposited to any extent until most of the urao has separated. Afterward the relative amount rapidly increases, as has been shown by the series of crystallizations of the water of Owen's and Mono Lakes.

The "crude," as already stated, is that portion of the first crystallization which was not redissolved. As the first crystallization was allowed to go on till NaCl had been deposited in some quantity, the

increased amount of this salt is accounted for; but as the process was then interrupted, little more sulphate is found in this than in the purest specimens.

The "twig" urao shows smaller differences from the theoretical proportions, than any of the others. The grass root on which it formed was suspended in the water of the shallow natural basin so that the crystallization proceeded evenly at all points. It was only when the decrease of the water left the specimen lying on a mud bank that the salt crystals and sand adhered to it. If these impurities are deducted, the remainder is a practically pure urao.

The "beach vat" made by spontaneous evaporation of a lye differing from the lake water in having a larger percentage of NaHCO_3 and a smaller proportion of Na_2SO_4 , is also very close in the relations of the urao constituents.

Finally we have the "lagune" urao. This was found on the border of the small lagune which was then dry. It is apparently the result of an interchanging concentration and dilution of the mother-liquor in which it was formed. As the water in such a shallow basin evaporates, the tendency is to leave a crust of very pure urao at the edge of the basin, the deposit towards the center becoming more and more impure as the concentrating liquid deposits its salt and sulphate, and becomes, as the experiments show, a comparatively pure solution of monocarbonate. If then the basin be refilled by seepage, as would be the case when the lake rises, as it does in the spring, the solution would contain a larger proportion of the neutral carbonate, and in consequence, on re-concentration, leave on its edges a urao containing an excess of hydrated monocarbonate. If we calculate the amount of urao present in this sample we shall find that the excess of Na_2CO_3 and H_2O is almost exactly the amount required for $\text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O}$.

"Lagune."	Urao.	$\text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O}$.
Na_2CO_3	48.73 = 39.73	+ 9.00
NaHCO_3	31.49 = 31.49	.... ....
H_2O	16.57 = 13.49	+ 3.06 + .02
Impurities	2.21 = ...	 2.21
	99.00 = 84.71	+ 12.06 + 2.22

The deficiency of one per cent. in the analysis is in this respect unfortunate, but can not be easily explained. The analytical figures given are averages, derived from two or more closely agreeing determinations of each constituent, the list of which comprises everything that can be supposably present.

Artificial urao.—In order to determine the conditions under which urao is formed, and also to find out if, by spontaneous evaporation, the sesquicarbonate or any other combination of the mono and bicarbonate might be formed, the following series of experiments was undertaken.

Some of the analytical results already obtained appeared to give some indications of the existence of a mixed carbonate having a formula $2\text{Na}_2\text{CO}_3 + \text{NaHCO}_3 + x\text{H}_2\text{O}$. If this could be separated in a pure state and the sesquicarbonate also obtained, we should have the following series:

Na_2CO_3	Mono-carbonate.
$\text{Na}_2\text{CO}_3 + \frac{1}{2} \text{NaHCO}_3$	Supposed salt.
$\text{Na}_2\text{CO}_3 + \text{NaHCO}_3$	Urao.
$\frac{1}{2}\text{Na}_2\text{CO}_3 + \text{NaHCO}_3$	Sesquicarbonate.
NaHCO_3	Bicarbonate

For this investigation a number of solutions were prepared, each of which contained Na_2CO_3 , NaHCO_3 , and NaCl , the amount of each salt employed having a certain definite relation to its molecular weight. NaCl was used because its presence appears to exert a favorable influence on the crystallization of the mixed carbonates.

Solution No. 1 was intended to produce the "supposed salt," and was therefore made up as follows: 10.5 grams NaHCO_3 ($=\frac{1}{2}$ molecule) 26.5 grams Na_2CO_3 ($=\frac{1}{2}$ molecule) were dissolved in water. To this solution were added 26.5 grams Na_2CO_3 and 29.25 grams NaCl . These latter amounts are purely empirical, an excess of Na_2CO_3 seemed to be needed, so that a quantity equal to that already present was added, and as we then have half a molecule, 29.5 grams $=\frac{1}{2}$ mol. NaCl was used. The solutions as evaporated contained:

No. 1.	10.05 grams $\text{NaHCO}_3 = \frac{1}{2}$ molecule.
	53.00 grams $\text{Na}_2\text{CO}_3 = \frac{1}{2}$ molecule.
	29.25 grams $\text{NaCl} = \frac{1}{2}$ molecule.
No. 2.	21.00 grams $\text{NaHCO}_3 = \frac{1}{2}$ molecule.
	53.00 grams $\text{Na}_2\text{CO}_3 = \frac{1}{2}$ molecule.
	29.25 grams $\text{NaCl} = \frac{1}{2}$ molecule.

This proportion was expected to yield urao:

No. 3.	42.00 grams $\text{NaHCO}_3 = \frac{1}{2}$ molecule.
	53.00 grams $\text{Na}_2\text{CO}_3 = \frac{1}{2}$ molecule.
	29.25 grams $\text{NaCl} = \frac{1}{2}$ molecule.

The amount of NaHCO_3 being twice as great as in No. 2, there was a possibility of the formation of sesquicarbonate.

In the course of six weeks No. 1 had deposited a crop of acicular crystals. The mother liquor was poured off, leaving a large group of small but good crystals, and a number of smaller groups. These were collected and carefully dried between filter paper, remaining perfectly transparent and unaltered in the air. In the course of another week the mother liquor yielded a second crop of acicular crystals.

No. 2 deposited at first some crystalline scales, afterwards acicular crystals were formed; this material was collected, and the scales were carefully separated from the other crystals.

No. 3 behaved like No. 2, except that the crop of scales was larger.

The salts thus obtained were analyzed, giving the following results.

The figures for No. 1 are averages of two closely agreeing determinations of each constituent:

	No. 1, first crop acicular.	No. 2, first crop scales.
H ₂ O.....	19.58	11.78
CO ₂	38.73	51.69
Na ₂ O.....	40.07	36.54
NaCl.....	1.46	.51
	99.84	100.52

Hypothetical combination.

H ₂ O.....	15.37	1.25
Na ₂ CO ₃	43.69	.42
NaHCO ₃	39.32	98.34
NaCl.....	1.46	.51
	99.84	100.52

By calculating the percentage of urao in each of these salts we find,

	No. 1.			No. 2.		
	Urao.	Bicarbonate.	Residue.	Urao.	Bicarbonate.	Residue.
H ₂ O	14.84	.....	.53	.14	.....	1.11
Na ₂ CO ₃	43.69	.....	.....	.42	.....	.....
Na ₂ HCO ₃	34.62	4.70	.....	.33	98.01	.....
NaCl .....	.....	.....	1.46	.....	.....	.51
	93.15	4.70	1.99	.89	98.01	1.62

We see therefore that No. 1, 1st crop, is urao, plus 4.70 NaHCO₃, while in No. 2, 1st crop, the scales are nearly pure bicarbonate.

The scales of No. 3 being in all respects similar to those of No. 2 and of No. 7 (to be described later), were considered as being NaHCO₃, and were not analyzed.

In the mean time other solutions had been prepared, in which not only the relative proportions of Na₂CO₃ and NaHCO₃ were varied, but also that of NaCl, in order that the proper proportions of a typical solution for the production of urao might be determined.

For this purpose a solution of Na₂CO₃ was prepared, 200 cm³ of which contained 53 grams of the salt, the amount taken for each experiment, the other salts being added, together with sufficient water to effect complete solution.

Solution.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.
Na ₂ CO ₃	53.00	53.0	53.0	53.0	53.00	53.00
NaHCO ₃	21.00	10.5	10.5	42.0	5.25	5.25
NaCl	58.5	14.62	58.5	58.5	58.5	29.25

In preparing No. 4, the NaHCO_3 was added in portions to the 200 cm^3 of Na_2CO_3 solution, which was vigorously shaken after each addition, but to effect complete solution it was necessary to add water until the volume measured 250 cm^3 . To this, the NaCl was added, and the whole again shaken; an emulsion was formed which speedily became solid, so that the vessel could be inverted without loss. Portions of water were gradually added until a clear solution was obtained, the resulting liquid measuring 590 cm^3 . With No. 5 the NaHCO_3 dissolved completely without addition of water, but on putting in the NaCl and making a solid mass resulted, measuring 220 cm^3 . Water was then added, and the final solution measured 300 cm^3 . The same phenomenon was observed with each of the other preparations, and all were allowed to spontaneously evaporate.

No. 4 deposited at first a quantity of scales, but soon began to form urao. The mother was then poured off and subsequently produced a large crop of urao, the mother liquor of which deposited NaCl in small but very brilliant cubes.

No. 5 formed radiating wisps or sheaves of very good and quite stout acicular crystals (No. 5, 1st crop.) The mother liquor continued to form these crystals and after some time was poured off. This second mother liquor produced in time several large masses of apparently tabular crystals, together with a small quantity of fine needles. These masses were collected, and as they showed a strong tendency to effloresce and a portion placed in a small bottle became partially liquefied at the atmospheric temperature of 32°C . (90°F .), there is no reason to doubt that they were the ordinary decahydrated salt $\text{Na}_2\text{CO}_3 + 10\text{H}_2\text{O}$.

No. 6 yielded a large crop of beautiful groups of radiating acicular crystals (No. 6, 1st crop). The mother liquor continued to form small acicular crystals, finally NaCl in cubes.

No. 7 deposited crystalline scales, and when acicular crystals began to form the mother liquor was poured off and the needles carefully separated from the plates (No. 7, 1st crop). The mother liquor yielded acicular crystals and NaCl .

Nos. 8 and 9 each deposited acicular crystals, and the mother liquor was poured off. The mother liquor of No. 9 formed a quantity of fine needles so matted together as to present a woolly appearance. (No. 9, 1st crop).

	No. 5, first crop acicular.	No. 6, first crop acicular.	No. 7, first crop scales.	No. 9, second crop acicular, matted.
H_2O	19.54	19.42	11.63	18.91
CO_2	37.88	37.76	51.52	36.46
Na_2O	41.02	39.85	36.40	39.32
NaCl	1.72	2.88	Undet.	5.58
	100.16	99.91	99.64	100.27

Hypothetical composition.

H ₂ O	15.96	15.55	.92	15.41
Na ₂ CO ₃	49.00	45.29	.64	46.00
NaHCO ₃	33.48	36.19	98.08	32.68
NaCl	1.72	2.88	Undet.	5.58
	100.16	99.91	99.64	100.27

Calculating the amount of urao as before, we get

	No. 5, first crop.			No. 6, first crop.		
	Urao.	Na ₂ CO ₃ ·H ₂ O.	Residue.	Urao.	NaHCO ₃ .	Residue.
H ₂ O	14.35	1.14	.47	15.38		.17
Na ₂ CO ₃	42.25	6.75		45.29		
NaHCO ₃	33.48			35.89	.30	
NaCl			1.72			2.88
	90.08	7.89	2.19	96.56	.30	3.05

	No. 7, first crop.			No. 9, second crop.		
	Urao.	+NaHCO ₃ .	+Residue.	Urao.	+Na ₂ CO ₃ ·H ₂ O.	+Residue.
H ₂ O	.22		.70	14.00	.91	.59
Na ₂ CO ₃	.64			41.24	5.36	
NaHCO ₃	.51	97.57		32.68		
NaCl			Undet.			5.58
	1.37	97.57	.70	87.92	6.27	6.08

The early products of the other solutions did not differ in physical properties from those examined, and were therefore not analyzed. The mother liquors, however, if allowed to evaporate till all the urao and most of the NaCl had been deposited, yielded crops of the monohydrated carbonate Na₂CO₃·H₂O, as was shown by analysis; but any considerable fall in the temperature of the solution caused a crystallization of the decahydrated salt.¹

From the results before us it is evident that no such compound as the sesquicarbonate is obtained from a solution of the two carbonates by spontaneous evaporation and crystallization, and no other compound carbonate but urao was produced in any of these experiments. If there is an excess of NaHCO₃ present this will separate first, but the next

¹ An abstract of these results was published in a paper on "Urao," in *Am. Jour. Sci.*, vol. 38, July, 1889, p. 59 seq. The crystals obtained as above were crystallographically examined by Mr. Edward F. Ayres, who published his results in the same number of the Journal. He shows that urao is monoclinic, but that the angles differ but slightly from those of orthorhombic forms, and quotes Zepharovich (*Zeitschrift f. Kryst.*, vol. 13, p. 135, 1887), who obtained similar results on a urao formed accidentally by Reinitzer, whose analytical determinations agree with my own. Reinitzer gives as *sp. g.* 2.14, my own determination being 2.1473.

product will be urao. As the urao crystallizes upon and intermixes with the previously separated bicarbonate, it is clear that unless the two are carefully separated an analysis of the product may give results ranging all the way from pure bicarbonate to pure urao, or ultimately the neutral carbonate. The variations in the analyses of natural soda are thus explainable, since the bottom part of a cake of such soda should generally be richer in bicarbonates than the rest. This will be still more likely if much NaCl is present in the solution, since, as shown by No. 6, NaHCO₃ was separated, although the proportion of Na₂CO₃ present was four times that required for urao. In No. 5 the proportion of NaHCO₃ or of NaCl is too low, as shown by the presence of Na₂CO₃ in the first crystallization. No. 9, which was considered a crucial test of the possibility of the formation of the "supposed soda," gave even as its second crop only urao, the amount of Na₂CO₃, however, being too small to be considered otherwise than as an impurity. The first products of No. 2 and No. 7 are NaHCO₃ almost pure, as was also No. 3, 1st crop, and No. 4, 1st. No. 2 differs from No. 4, as does No. 7 from No. 3, only in having one-half the quantity of NaCl; all of the deposited NaHCO₃, but No. 2 less than the others.

No. 1, which in amount of NaCl is midway between Nos. 5 and 6, shows more NaHCO₃ than No. 6, but less NaCl. In this case the amount of NaCl in the solution was not sufficient to separate NaHCO₃ until the solution had become sufficiently concentrated to deposit urao when both salts crystallized together. This is indicated by No. 1, where the increase in the amount of NaHCO₃ had the effect of depositing a portion of it before the urao had formed.

That the presence of NaCl is not necessary for the formation of urao was proved by the following experiment. A saturated solution of chemically pure sodium carbonate was prepared, and into this pure carbonic acid was forced under pressure until a considerable amount of bicarbonate had been deposited. The solution was then filtered and put aside to evaporate spontaneously. No further separation of NaHCO₃ was observed, and in time a crop of acicular crystals was obtained which on analysis yielded the following results:

			Urao.	Na ₂ CO ₃ H ₂ O.	Residue.
H ₂ O.....	20.14	H ₂ O.....	16.33 = 15.21	+ .59	+ .53
Na ₂ O.....	41.40	Na ₂ CO ₃	48.35 = 44.85	+ 3.50	..
CO ₂	38.69	NaHCO ₃	35.55 = 35.55	....	..
	100.23		100.23	95.61	4.09 .53

The salt is therefore urao with a small proportion of Na₂CO₃, H₂O. The residue of water is very nearly sufficient for the dihydrated soda, but in view of what has been already shown it is more reasonable to consider it as an excess. It will be observed that no tendency to form sesquicarbonate is evinced, although it would seem that the circumstances were most favorable for its production,

Experiment has also shown that if a moderately concentrated solution of pure Na_2CO_3 be exposed to the air until crystallization begins, the first crystals obtained are urao, owing to the absorption of CO_2 from the air during the slow evaporation. It is therefore very remarkable that the voluminous literature of soda takes such slight notice of this salt, which must have been so frequently seen by those working with soda salts.¹ Even Lunge's great work mentions urao but once, and then only as a synonym for trona, although its nature and properties would appear to give valuable hints for technical work.

As has been already seen, Wallace had a suspicion that such a compound existed, but Mondesir² has the credit of being the first to publish a method for its production in a pure state. After alluding to the doubts concerning the nature of "sesquicarbonate," he gives an account of his work on the mineral waters of Royat, in the course of which he established the presence of urao. In describing it he says:

This salt is very stable in saturated solutions of NaCl probably because it is only slightly soluble even with the aid of heat, and even on boiling loses its acid carbonic acid with excessive slowness. Nevertheless a certain excess of the neutral carbonate is necessary for its preservation.

His method of preparation is to dissolve 28 parts of NaCl and 28 parts of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ in 100 parts of water. The solution is then heated nearly to boiling and a thoroughly incorporated mixture of 8 parts NaHCO_3 and 28 of $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ is gradually added in small portions, the liquid being continually stirred, and the loss by evaporation being made good by addition of distilled water. As soon as the solution is complete the liquid is allowed to cool slowly, when the urao crystallizes in fine needles. He advises that the temperature of the liquid should not be permitted to go below 20°C . (68°F). The salt crystallizes in fine needles matted together, and when treated with water, is decomposed, Na_2CO_3 going into solution, while NaHCO_3 is undissolved.

To this salt, which he recognizes as being the same as Boussingault's urao, he gives the name "carbonate quatre-tiers," or "four-thirds carbonate," on account of the relation of CO_2 to Na_2O . In the sesquicarbonate we have the relation of one and one-half equivalent of CO_2 to one equivalent of Na_2O , whence its name, while in urao the relation is four-thirds of an equivalent of acid to one of base. It might, therefore, be called the "tetra-trita" or "tetrита carbonate."

Mondesir's view that the presence of NaCl and excess of Na_2CO_3 is of value in the formation of the salt is in harmony with my own results, though my work shows that the NaCl is not absolutely necessary, and that the aid of artificial heat can be dispensed with unless the atmospheric temperature is below 20°C . If the solution is cooled down below that point, the excess of Na_2CO_3 is liable to crystallize out as the decahydrated salt.

¹ See note on p. 82 concerning Reinitzer's work.

² Mondesir, Paul de: *Comptes Rendus*, Mai 31, 1887, civ. 22, p. 1505.

ANALYTICAL METHODS.

The analytical methods employed in these analyses are in general well known. The salts and solutions necessarily contain only traces of other bases beside alkalies, and those were determined in the usual manner. Silica may exist in some quantity, but the amount is usually small.

SO₂ and Cl were determined gravimetrically and in duplicate, the results agreeing in most cases very closely. When SO₂ is precipitated by BaCl₂ in such solutions containing alkaline salts only, and these in small quantities, and care is taken that the precipitant is in slight excess only, the precipitation is both rapid and complete and the precipitate is pure, the after treatment with HCl rarely showing a loss of any consequence.

The CO₂ was determined by distillation, the gas being collected and weighed in a Liebig potash bulb, and the apparatus and method are fully described in "Analyses of waters of the Yellowstone National Park." Gooch and Whitfield, Bulletin No. 47, U. S. Geol. Survey, p. 15. With care and experience the results agree very closely. For the boric acid, in the water of Owen's Lake, the excellent method of Gooch¹ was followed; for the Mono and Ragtown waters the process of Stromeyer, with modifications of my own, was used; but, though giving very fair results, the process can not be compared for ease, simplicity, and accuracy with the former method.

The determination of the alkalies in such very dense waters was, at first, found to be difficult, owing to the large quantities necessarily taken. To get determinations which shall be fairly accurate when referred to a liter, portions of not less than 50cm³ should be taken, the water in all cases being carefully weighed. The amount of alkaline chlorides corresponding to 50cm³ of such waters is very large, and, when the final evaporations are being made, there is great liability to loss, owing to the formation of a salt crust on the surface of the liquid and subsequent spirting, caused by steam and ammonia vapor produced under the crust. This takes place no matter how carefully the evaporation be carried on, and many determinations were thus lost.

The use of hydrochloric acid enables us, however, to completely obviate this difficulty. The purified alkaline chlorides are to be evaporated till crystallization begins; the platinum vessel is then removed from the water bath, and an equal bulk of very pure, highly concentrated hydrochloric acid added to the solution. A copious precipitation of finely granular salts at once ensues, and, on replacing the vessel on the water bath, evaporation goes on quietly and rapidly, no salt crust is formed, and when the final heating is given, little decrepitation occurs. In this manner it is as easy to handle several grams of

¹ Gooch: Proc. Am. Acad. Sci., 1886, p. 167.

chlorides and to obtain accurate determinations as it is when we have to deal with the far smaller quantities usual in mineral analysis.

The water in the salts was determined by means of the apparatus figured. A is a combustion tube drawn out and bent at a right angle. The platinum boat B, containing the salt, rests upon the thin sheet of asbestos paper C, used to prevent adhesion between the platinum and the heated glass. D is a roll of asbestos paper wrapped with thin platinum wire, which fits loosely in the tube and prevents back currents of air during the heating. The bent end of the combustion tube enters one limb of the U tube E, which is my own form, and differs, as the drawing shows, materially from the forms now on the market, in having an especially large bulb at the bottom. The two limbs of this tube are filled with glass beads wet with strong sulphuric acid. Sufficient acid should be put in so that the narrow tubes are filled up to the bends and the air forced to bubble through.

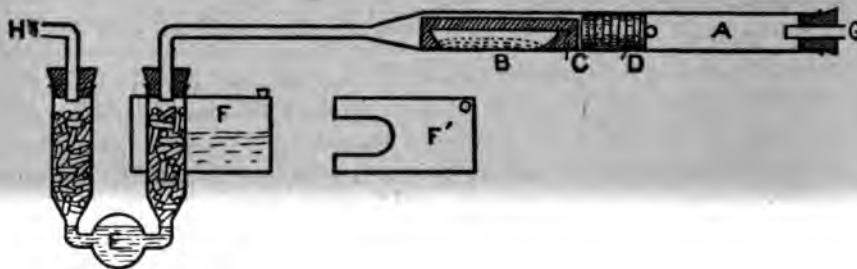


FIG. 4.—Apparatus for determination of water.

In using the apparatus the tube is thoroughly heated and then allowed to cool, a current of perfectly dried air being continually passed through it. The part of the tube where the boat is placed is protected by a semi-cylinder of sheet-iron lined with asbestos paper.

The U tube, having been weighed, is then attached to the combustion tube as shown and the air current regulated. The platinum boat which has been heated and then cooled in a desiccator, is now weighed and about one gram of the salt put into it and spread evenly along the bottom. The salt should be very finely pulverized to prevent decrepitation on heating. The boat with its contents having been weighed, it should at once be inserted into the tube and the asbestos plug D which has been highly heated and should still be hot, shoved in close behind the boat.

The tube is now heated gradually, beginning at the plug. As the water in such salts is driven out in great part at a low temperature the heating must be done cautiously and the air current watched, since, if it is too slow, water may condense in the cold part of the tube behind the plug. This regulation of the air current is the more difficult, since the acid CO_2 of the bicarbonate is set free simultaneously with the

water, but upon it and the gradual heating depends the success of the operation.

The water bath F, of which F' is a top view, is now put into position, so that one limb of the U tube fits into the curved recess in the side of the bath. A small alcohol lamp keeps the bath hot, so that the water driven out of the salt may not condense in the upper part of the limb. By the use of this bath the time of the operation is much shortened.

As soon as that part of the tube containing the boat appears free from condensed water it should be highly heated until all the moisture has disappeared from the drawn-out portion. This will generally take from twenty minutes to half an hour, and when completed the water bath is removed and the apparatus allowed to cool, the air current being still kept up. As soon as the tube is cool the U tube is disconnected and the boat removed and placed in a small, well-stoppered glass tube, which has been weighed. The increase of weight of the U tube gives the amount of water in the sample, while the weight of the small tube containing the boat and calcined salt, if subtracted from the sum of the weights of the boat, the salt taken and the weighing tube shows a loss which is the water plus the acid CO_2 of the bicarbonate. The calcined salt which should be sintered together, but not fused, can then be used either for a determination of the residual CO_2 or, as is usually done, dissolved and the alkali determined by standard sulphuric acid, methyl orange being used as the indicator, the same portion being then used for the Cl determination.

Many attempts were made to collect and weigh the CO_2 driven off by heat, but it was found impracticable to do so without at the same time sacrificing the water determination. No matter how carefully the heat and air current are regulated, the CO_2 comes off too rapidly for proper absorption in the potash bulb, and if the air current is too slow, water condenses back of the plug and this determination is too low.

When no attempt is made to absorb the CO_2 , the results are very satisfactory. In the analysis of urao "best specimen" given on page 76, we have as the mean of three closely agreeing CO_2 determinations 38.13 per cent., while two determinations of the alkali gave 40.28 per cent., equivalent to 28.58 per cent. of CO_2 required to make monocarbonate. Deducting this amount from that of the total CO_2 we have 9.55 per cent. as the acid CO_2 of the bicarbonate present. The determinations with the above described apparatus gave the following results:

Salt taken.	Loss of boat.	H_2O .	Difference = CO_2 .
1.0040	29.51	20.12	9.39
1.0490	29.58	20.09	9.49
1.1583	29.49	20.00	9.49
1.0638	29.53	20.07	9.46

We have therefore as average 9.46 per cent. CO_2 found, which being deducted from the calculated amount 9.55, leaves an excess of 0.09 per cent. not driven off.

In another sample of urao:

Salt taken.	Loss of boat.	H_2O .	Difference = CO_2 .	CO_2 in residue.	Sum of CO_2 .
1. 1801	29.27	19.80	9.47	28.69	38.16
1. 2297	29.35	19.83	9.52	28.64	38.16
1. 2066	29.39	19.85	9.54	28.49	38.03
1. 0880	29.26	19.80	9.46	28.67	38.13
1. 1761	29.32	19.82	9.50	28.62	38.12

Two determinations of total CO_2 gave 38.17 and 38.22 per cent.—average 38.19. Two determinations of alkali gave 40.19 and 40.22 per cent. Na_2O , average 40.20—equivalent to 28.53 per cent. CO_2 . Hence, as 28.62 per cent. CO_2 was found in the residue and only 28.53 was necessary for the combination Na_2CO_3 , we have $28.62 - 28.53 = 0.09$ per cent. CO_2 not driven off.

In a sample of Trommsdorff's C. P. sodium bicarbonate there was found:

Salt taken.	Loss of boat.	H_2O .	Difference = CO_2 .	CO_2 in residue.	Sum of CO_2 .
1. 4265	36.68	10.91	25.77	-----	-----
1. 5995	36.81	10.90	25.91	-----	-----
1. 3200	36.71	10.91	25.80	26.25	52.05
1. 3723	36.73	10.98	25.75	26.37	52.12
1. 4296	36.73	10.92	25.81	26.31	52.09

Two determinations of total CO_2 gave 52.06 and 51.90, average 51.98 per cent. Two determinations of alkali gave 36.86 and 36.90, average 36.88 per cent. Na_2O , equivalent to 26.17 per cent. CO_2 . Subtracting 26.17 from 26.31, the average amount in the residue, we have 0.14 per cent. CO_2 not expelled by heating to the sintering point.

Comparing these amounts of excess of CO_2 retained by the residues of the ignition, we find the following relation:

Sample.	Number of determinations.	Average weight taken.	Average excess, per cent.	Relation of excess to weight.
Urao, No. 1.	3	1. 0638	0.09	0.084
Urao, No. 2.	4	1. 1761	0.09	0.077
Bicarbonate.....	4	1. 4296	0.14	0.091
Average.....	-----	-----	-----	0.084

Hence we may say that if sodium bicarbonate, or a salt containing a large proportion of it, is heated till it sinters without fusing, and is kept at that temperature for one hour, it still retains CO_2 in excess of the amount required to form monocarbonate with the alkali present,

and that for quantities of from 1 to 1.5 grams this excess may be considered as one-tenth of one per cent. of the weight of the salt taken.

For an analysis of sodium bicarbonate by means of this method is therefore sufficient to determine the loss by ignition, the H_2O , and the alkali in the ignited residue to obtain the total amount of CO_2 in the sample, adding in an amount of CO_2 equal to 0.10 per cent. of the weight of the salt taken. This method for the analysis of bicarbonate or "baking soda" is much more rapid, far easier and quite as accurate as the distillation process, and may prove of value for technical purposes.

ORIGIN OF NATURAL SODA.

We have seen that this material occurs in many widely separated localities, which have, perhaps, but one characteristic in common, namely, a very dry climate. The presence of volcanic rocks belongs to late geologic periods, though proved in many instances, has not yet been shown for a few of them, such as Hungary and Egypt.

Dryness of climate has no other effect, probably, than to retain within a given region its product of natural soda, which would otherwise be continually carried off to the sea through natural drainage, though the consequent inclusion of the drainage in closed basins may be necessary to permit of certain chemical after-reactions.

In an arid region like our Great Basin, but a small portion of the total rainfall reaches the ocean. Rivers of considerable magnitude terminate in "sinks" or lakes without outlet. Such lakes are naturally impregnated with salts, since each drop of inflow brings its quota, and the only loss that such a basin suffers is by evaporation, which carries off no solid matter.

Unless chemical changes occur in the lake itself, such a body of water represents a simple concentration of its inflowing streams, and if we find it to contain any given salt, it is evident that this salt has either been brought as such into the basin, or is a product of chemical after-reactions among the constituents of the lake water. If the salt has been brought as such it is a product of rock or soil decomposition, and is in solution as a result of a leaching process, whether the water came from a deep-seated spring or is a mere surface drainage.

The existence of springs carrying sodium carbonate is well-known, since many of them have a world-wide reputation for their medicinal qualities. Although most of them are weak solutions, a comparison of their compositions with those of the waters described in this paper will show that they would by sufficient evaporation yield a very pure natural soda. The sodium carbonate in such springs is produced by decomposition of the alkali-bearing rocks through which the water flows, and this decomposition is brought about by the combined action of air and moisture, aided in many instances by heat and pressure.

The air absorbed by water contains a much larger proportion of

gen and carbonic acid than the normal atmosphere, the composition of which may be taken as

Oxygen.....	20.9512
Nitrogen.....	79.0073
Carbonic acid.....	0.0415

while the air absorbed by water at 15° C. (60° F.) contains, according to Bunsen,

Oxygen.....	34.12
Nitrogen.....	63.62
Carbonic acid.....	2.26

The alkali-bearing minerals are generally silicates, having for bases ferrous or ferric oxide, alumina, lime, magnesia, soda and potash in varying proportions according to the character of the mineral. Thus orthoclase feldspar is composed, essentially, of silica, alumina and potash; albite, of silica, alumina and soda; anorthite, of silica, alumina and lime, but they are rarely found pure and there exist many intermediate steps, so that orthoclase usually contains soda and lime in varying proportions, while magnesia and ferric oxide replace in part lime and alumina respectively.

By the action of water, containing carbonic acid, upon such minerals, the alkalies and alkaline earths are converted into carbonates and dissolve in the carbonated water. Hence they are leached out of the residue, which is rendered the more porous through the decomposition, and if the water so charged does not on its way to the surface meet with sulphates or chlorides of other metals which, by double decomposition, would produce alkaline sulphates or chlorides and non-alkaline carbonates, the alkaline carbonates make their appearance as constituents of a mineral spring. In such springs the salts of sodium are usually in much greater proportion than those of potassium, not only because the soda minerals are, in general, more easily decomposable, but also because soils have a strong tendency to take up and retain the potash salts from water percolating through them while readily giving up their contents of soda salts.

If the waters of such springs flow into basins without outlet and the rate of evaporation equals the inflow, a concentrated solution gradually results, and if the inflow be interrupted, we shall in time have a dry basin in which the salts have deposited as a crystallized mass. It is evident that if the geological character of a country is favorable to the production of such alkaline springs, the dryness of the climate or the excess of evaporation over rainfall determines the degree of concentration of the contents of their basins, the number of which is dependent on the topography, and the consequent productiveness of the region in natural soda.

We have so far considered original formation and simple evaporation only. There are, however, a number of instances in which the alkali appears to be the result of more complicated chemical reactions. We have already seen the views of Szabo and Moser as to the mode of

origin of the Hungarian soda, in which the carbonate of lime is supposed to play a part. Lunge¹ refers to the fact that from a damp mixture of common salt and lime soda effloresces, in the air after several weeks' time, and also states that "from a solution of common salt a solution of bicarbonate of lime precipitates sodium bicarbonate; apparently this reaction explains the formation of soda efflorescence in soils containing common salt." If the more soluble magnesium bicarbonate be substituted for the calcium salt we have Weldon's process for soda making.

It may therefore be said that if common salt and limestone or dolomite are present together in a soil, subject to the action of air, moisture and climate, all the conditions for the production of natural soda are at hand, and it is thus that the origin of the soda of Egypt may be explained. Russegger's description of this locality has already been cited. After ascribing the formation of the sodium carbonate to reactions occurring between the CaCO_3 , Na_2SO_4 and NaCl , by which Na_2CO_3 , CaCl_2 and CaSO_4 are formed, he says:

The first two (Na_2CO_3 and CaCl_2) dissolve in the water of the lakes together with the undecomposed Na_2SO_4 and NaCl , and thus we have a lye containing NaCl , Na_2SO_4 , Na_2CO_3 and CaCl_2 .

A very slight knowledge of chemistry tells us that Na_2CO_3 and CaCl_2 cannot exist together in solution, since CaCO_3 must be precipitated at once, NaCl remaining in solution; so Karsten (loc. cit.) adds the following note:

This transformation of the salts is undoubtedly a consequence of the oxydation of the pyrites in the clay to sulphates, followed by a double decomposition of these sulphates by the NaCl and CaCO_3 in the clay. The sodium and calcium sulphates so formed are then reduced to sodium and calcium sulphides and these are decomposed by means of NaCl and CaCO_3 . The process must, therefore, be considered as very complicated and as demanding not only length of time but also a co-operation of special conditions, precisely as they occur in the Egyptian lakes. The organic matter here present may well be considered as the sole and only cause whereby the sulphates are reduced to sulphides, these being changed then to carbonates.

Abich, in his description of the Armenian localities, already given in part, ascribes the formation of the sodium carbonate there found more particularly to the action of plant life. The salt grasses and other plants which grow in that region yield an ash rich in soda salts, those from Armenia being richer in Na_2CO_3 , while those from the Steppes contain a larger proportion of Na_2SO_4 . The soil of the Steppes contains much Na_2SO_4 , but is poor in NaCl , precisely the reverse of the soil of Armenia; hence the conclusion that the Na_2CO_3 is formed by the action of the plant on NaCl , comparable with the formation of potassium carbonate, which usually predominates in the ash of land plants. The growth, death and decomposition of successive crops of such plants would, under this view, continually increase the amount of sodium carbonate in the soil without taking into consideration the amount pro-

¹ Lunge: Sulph. Acid and Alkali, Vol. 2, p. 310.

duced by direct weathering of the eruptive rocks so abundant in that region.

We have already seen that the deposits of Wyoming consist in great part of sulphates and chlorides, though occasionally the percentage of carbonate becomes sufficiently large to be of importance. This is also true of the Lake Bonneville region as described by King in the 40th Parallel report, already frequently quoted. In vol. 1, page 500, he shows that the salts are mainly chlorides and sulphates, the former largely predominating, while carbonates are generally absent. The water of the Great Salt Lake may therefore be taken as typical for the region. As one proceeds westwardly the occurrences of alkaline carbonates are more frequent and the percentage of this salt greater until we reach the Lahontan region of western Nevada, where the proportion of alkaline carbonate is usually greater than that of sulphate.

The cause of this chemical change in the nature of the salts, though much discussed, is not yet ascertained. So far as we know, there is no such difference between the rocks of the eastern and the western portion of the Great Basin as would account for this increase of the carbonate. In both sections the eruptive rocks are of similar character, and, by their decomposition, should yield the same products. It is possible that the fact that volcanic action has persisted to a much later date on the western border than on the eastern side may have some influence. Hot springs are much more common along the foot of the Sierra Nevada, and some of the volcanoes have been active at a comparatively recent date. The enormous volume and high temperatures of the heated waters of the Comstock Lode may also be considered as showing a probably greater activity in rock decomposition but not, necessarily, a difference in character of product.

Once formed through rock decomposition, a solution containing sodium chloride, sulphate and carbonate would afterwards lose none of its carbonate unless soluble earthy salts were added to it; on the contrary, when such a water reaches an enclosed basin, the proportion of sodium carbonate tends, following the views of Karsten, to increase through the reduction of the sulphate by organic matter and the subsequent action of the atmospheric carbonic acid on the sulphide; a reaction which requires a period of comparative rest, which such a basin affords. It has been already stated that the waters of springs carrying alkaline carbonate may lose the whole of it on the way to the surface by passing through formations containing non-alkaline soluble salts, such as gypsum, calcium chloride or magnesium salts, resulting in the formation of calcium or magnesium carbonate and alkaline sulphate or chloride. The same reaction would occur if the surface water percolates through soils containing these salts, or if water containing them be added to the streams or basins.

It is probable that an alkaline lake or the dry deposit resulting from *its* desiccation is in all cases the result of both primary rock decomposition and subsequent chemical change. The latter usually appears to be the

ordinate agent, but still occupies a definite position, and in this connection the results of the examination of certain seepage waters from the area of Owen's Lake are interesting. The analysis of the water of the lake shows that sulphides are absent, the most careful tests showing merely a doubtful trace. On page 76, a urao was described as having been produced from seepage water collected in a vat dug on the shore and for practical reasons it was desirable to study the nature of the seepage. To this end, small pits were dug in a line extending from the vat to a point much above the highest recent water mark of the lake. From each of these pits, beginning with the one most distant from the lake, a sample of the seepage water was taken and the specific gravity tested, as follows:

Sample.	Temperature. ° C.	Specific gravity.	Remarks.
No. 1.....	32	1.005	
No. 2.....	31	1.035	
No. 3.....	31	1.050	
No. 4.....	31	1.050	
No. 5.....	32	1.062	Analyzed.
No. 6.....	32	1.090	
No. 7.....	32	1.108	
No. 8.....	31	1.085	Analyzed.
No. 9 near vat.....	31	1.063	Do.
Lake water.....	25	1.062	

The soil of these pits showed no variety; in each case it was found that the surface sand was underlaid by a dark grey material similar to dry sandy clay and closely resembling the "volcanic ash" common in this section, and which it is considered to be. A sample was taken from pit No. 9 and analysed as follows, having been partially dried, so that it became pulverulent and of a pale yellowish grey color.

H ₂ O at 110°.....	.65	H ₂ O.....	3.15
H ₂ O at red heat.....	2.50		
CO ₂ in soluble part.....	.87	<i>Soluble part.</i>	
CO ₂ in insoluble part.....	6.35	NaCl.....	1.45
SO ₃	.45	Na ₂ SO ₄	.80
Cl.....	.88	Na ₂ CO ₃	2.09
SiO ₂	55.81		4.34
TiO ₂	.80	<i>Insoluble part.</i>	
P ₂ O ₅	.27	CaCO ₃	14.44
Al ₂ O ₃	10.07	SiO ₂	55.81
Fe ₂ O ₃	3.43	TiO ₂	.80
FeO.....	.67	P ₂ O ₅	.27
MnO.....	.23	Al ₂ O ₃	10.07
CaO.....	9.14	Fe ₂ O ₃	3.43
MgO.....	2.22	FeO.....	.67
K ₂ O.....	2.98	MnO.....	.23
Na ₂ O.....	3.09	CaO.....	1.05
	100.41	MgO.....	2.22
O=Cl.....	.20	K ₂ O.....	2.98
	100.21	Na ₂ O.....	.76
			78.28
			100.21

Analyses of the samples of seepage water.

Specific gravity and temperature.	Pit No. 5.		Pit No. 8.		Pit No. 9.	
	1.06872 (22.5° C.)		1.0881 (24.1° C.)		1.07308 (21° C.)	
In 1 liter.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.
Cl.....	24.316	27.92	29.412	25.87	23.808	25.84
SO ₃	6.002	6.99	8.664	7.62	4.936	5.36
O.....	1.216	1.46	1.732	1.52	.988	1.08
S (sulphur).....	trace.....	.....	.120	.11	.161	.17
CO ₂	15.172	17.42	21.100	18.56	19.320	20.97
O.....	5.516	6.33	7.672	6.75	7.024	7.63
K.....	2.352	2.70	2.612	2.30	2.620	2.20
Na.....	32.064	36.82	41.896	36.85	33.426	36.24
SiO ₂	0.296	.34	.316	.28	.260	.29
Al ₂ O ₃	undet.....	.....	.008	.007	.008	.01
Ca.....	undet.....	.....	.020	.02	.014	.015
Mg.....	undet.....	.....	.009	.008	undet.....	.....
B ₂ O ₃	present.....	.....	undet.....	.....	undet.....	.....
H.....	.072	.08	.120	.105	.176	.20
	87.096	100.00	113.681	100.00	92.142	100.00

Hypothetical combination.

	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.
SiO ₂	.296	.34	.316	.28	.260	.30
Al ₂ O ₃.....	.....	.....	.008	.....	.008	.....
CaCO ₃.....	.....	.....	.044	.08	.032	.04
MgCO ₃.....	.....	.....	.033	.....	.....	.....
KCl.....	4.487	5.15	4.991	4.39	3.864	4.19
NaCl.....	36.549	41.96	44.545	39.18	36.199	39.28
Na ₂ SO ₄	10.812	12.41	15.376	13.52	8.757	9.49
Na ₂ S.....	trace.....	.....	.292	.26	.392	.43
Na ₂ CO ₃	28.876	33.17	37.884	33.33	27.817	30.19
NaHCO ₂	6.076	6.97	10.192	8.96	14.813	16.08
	87.096	100.00	113.681	100.00	92.142	100.00

In comparing these analyses we must remember that the water here examined is not the lake water, but the drainage from fresh springs along the base of the Inyo Range. As the water passes through the volcanic ash it gradually becomes laden with the salts produced by the decomposition of the soil as shown by No. 5. At this point the amount of sulphur or sulphuretted hydrogen present, though small, was unmistakable, showing that a reduction of sulphates had begun. In No. 8 the percentage of chlorides had diminished, and that of bicarbonate had increased, while the percentage of sulphates was somewhat larger, although sulphides were present in weighable quantities. No. 9 is very regular in its results if compared with No. 5. The chloride and sulphates have suffered a considerable decrease, while sulphides are in

as large a proportion as we should expect, considering that they would be destroyed at once if in solution with bicarbonates. The sodium monocarbonate is apparently less in amount than in the first analysis, but we observe a great increase in bicarbonate, so the percentage of alkali in the last analysis shows a large gain over the first one. As the distance from one pit to the next was not more than a hundred yards, this process of alkali production is really quite a rapid one, and the solutions obtained are stronger and of better quality for practical purposes than the mass of the lake water.

CAUSE OF THE RED COLOR OF CONCENTRATED ALKALINE BRINES
AND OF THE SALTS OBTAINED FROM THEM.

The red color which brines, particularly those of an alkaline character, are apt to assume when concentrated, and which is frequently taken up by the deposited salts, has often been noticed. The cause of this color has been studied by Payen,¹ who finds that it is due to the presence of the small crustacean, *Artemia salina*, Leach (*Cancer salinus*, Linn.), known in the West as the "alkali shrimp." In his experiments carried on at the Salines of Marignano, he found that the brine in concentrating to 15° B. becomes entirely clear and colorless, continuing until it reaches 20° B., at which point large numbers of small animals, grey or greenish grey in color, are observed swimming in the liquid. As the brine concentrates to nearly 25° B. all of these little crustaceans lie, turn red, come to the surface and form a red foam, which is composed of the fragments of their bodies and gives a peculiar odor. Experiments showed that if the concentration of the brine did not exceed 20° B. the animals were healthy, provided that they had air and that the solution did not become acid. If the solution became acid, the animals became sluggish and moribund, but were revived as soon as the solution was rendered alkaline.

The same may be said of the brine at 15° B. For a short time the animals were very lively, but on the fourth day became sluggish. Rendering the solution alkaline revived them to some degree, and on reducing a portion of the solution to 3° B. the crustacea in it remained alive and vigorous up to the time when the paper was written.

Those in the solution at 20° B. were lively during two days, then began to die, and all were dead on the third day. In fresh water all died within four days. In solutions at 23° B. all died within twenty-four hours, having become much redder than in the weaker solutions, and settled on the bottom as a brown sediment. These experiments show that a certain degree of concentration and a certain degree of alkalinity are necessary for the life of these animals, and that greater concentration causes death and the consequent red coloration.

The letter of Audouin accompanying the paper gives the observa-

¹ Payen: Ann. de Chimie, pt. 2, vol. 65, pp. 156-169.

tions of Schlosser made at Lymington, England, in October, 1755. The latter describes these animals as follows:

The body is merely a tube, cylindrical or vermicular in form, very slender, and about one-third of an inch in length. At one end of this tube are two antennæ, very delicate and short, and two black eyes, round and elevated; between these eyes is a black spot, which may be a third eye. A curved mouth is placed under the eyes. The body is provided with 21 pairs of natatory legs, the longest being in the center of the body, the others becoming shorter as they approach the head and tail. The posterior part is bare, the anus being at the extremity. The females have posterior to the last pair of legs a sac, usually three or four times the diameter of the tube, containing eggs; the males have, anterior to the first pair of legs, two long flattened arms, with these they seize the females, and while attached to them appear to squeeze out several eggs. The animals thus attached swim together for some time.

D'Arcet observed the red color of the Egyptian lakes, but finding only a few artemia, did not consider that the color was due to them. In the West the artemia are very plentiful and the red color is very usual, though generally ascribed to some property of the salt grasses. It is probable that the opinion of Payen is the correct explanation.

LEACHING OF ALKALINE SOILS AND CLAYS.

A chemical examination of a soil always includes a leaching with water and the analysis of the soluble portion. This is especially necessary in the case of samples from alkaline terraces, where the percentage of soluble salts is often large, and unless these can be extracted without alteration, no correct conclusion can be drawn as to the character and agricultural possibilities of the soil. In such regions crops can seldom be grown without irrigation, which not only supplies the plants with the necessary moisture, but also improves the land by leaching out the surplus salts, which may, under exceptional circumstances, be profitably recovered from the leachings.

The extraction of the soluble constituents from such soils and clays is often difficult, because when the sample is mixed with water subsidence is exceedingly slow, and filtration, if at all practicable, yields a very turbid solution. Having to examine a number of such samples, experiments were made to find out the simplest method of securing a clear aqueous solution containing only the naturally soluble salts. The persistent turbidity seems to be in some way connected with the alkalinity of the solution, since if this is rendered slightly acid, subsidence is rapid and a clear liquid is easily obtained. By acidifying, however, all the carbonates are decomposed and the resulting solution tells us nothing concerning the character of the original material.

It is well known that sea water precipitates the finely divided suspended material from inflowing river waters, and experiments based on this observation have shown that the addition of a small proportion of pure sodium chloride is all that is needed to obtain a clear and unaltered solution. Three samples of so-called "clays" from Owen's Lake have been especially examined for this purpose.

In making vats at the soda works at this place it was found that some of them could not be rendered water tight without great expense, and the reason of this was sought. Sample No. 1 represents this class of ground, while the combination of Nos. 2 and 3 is "good ground," holding water without difficulty. If the samples are dried the difference is strongly marked, No. 1 becoming very friable, while the others are as tenacious as a brick clay of inferior quality. If the dried samples are mixed with a little water all become pasty, but if much water is added the emulsion of No. 1 subsides rapidly, a few hours being amply sufficient to give a clear supernatant liquid, which can be poured off without disturbing the compact underlying sediment. Under like conditions Nos. 2 and 3 remain turbid, and after the lapse of thirty days not more than one-tenth of the supernatant liquid was even approximately clear. By the addition of a sufficient amount of common salt the subsidence was rendered as rapid and as complete as in No. 1, and the sediments can be washed by decantation. For the determination of chlorine, dilute nitric acid is added till the solution becomes acid, producing the same effect as the addition of common salt.

No. 1 is from the "upper works" at Keeler, Owen's Lake. It is covered by the surface sand, is yellowish grey in color and, as stated, friable. No. 2 is "sandy clay" from the "central works." This is immediately under the surface sand, is about 12 to 18 inches thick, and is said to be the best for vat-making; underlying this is the "blue clay," No. 3, of undetermined depth and also very good. Analysis gave the following results:

	No. 1.	No. 2.	No. 3.		No. 1.	No. 2.	No. 3.
H ₂ O at 120°	4.02	1.41	2.05	Water	5.08	4.14	4.45
H ₂ O at red heat. . .	1.18	2.73	2.40	Soluble part	24.80	1.26	1.41
SiO ₂	45.83	53.24	54.92	CaCO ₃	6.18	19.07	15.34
TiO ₂	.30	.25	.30	Insoluble	63.79	76.03	79.29
Al ₂ O ₃	8.05	10.81	11.25		99.85	100.50	100.49
Fe ₂ O ₃	2.77	2.59	2.77	<i>Composition of soluble part.</i>			
FeO	.43	.77	.94	Soluble.	No. 1.	No. 2.	No. 3.
MnO	.12	.10	.08				
CaO	4.88	9.18	8.76	KCl	4.19	.....	.....
MgO	1.23	5.82	4.91	NaCl	11.15	.09	.....
K ₂ O	2.86	2.64	2.77	Na ₂ SO ₄	3.30	.14	.....
Na ₂ O	14.21	2.06	2.10	Na ₂ CO ₃	7.50	.87	1.18
SO ₃	1.85	.08	trace.	NaHCO ₃	1.17	.....	.....
Cl	7.33	.05	trace.	SiO ₂	.39	.16	.23
CO ₂	6.44	8.75	7.24	Al ₂ O ₃	.11	.....	.....
	101.50	100.51	100.49		24.80	1.26	1.41
Deduct	1.65	.01	.49				
	99.85	100.50	100.00				

No. 1 is evidently in great part sand, made up of quartz and small grains of eruptive rocks, and contains but little real clay. Hence it absorbs large quantities of soluble salts, but parts with them readily on leaching, leaving a porous residue, which, on account of its granular condition, subsides rapidly when mixed with water. Nos. 2 and 3 contain only small quantities of soluble salts, but chlorides are practically absent, and the residues containing considerable quantities of carbonate of lime may be viewed as marls.

The clarification by the use of NaCl must be considered as a physical phenomenon since, so far as our present knowledge extends, no chemical change is supposable under the conditions. In each of the following experiments, begun September 11, 1888, the air dried material was weighed out and put into a cylinder containing the given amount of salt dissolved in 50cm³ of water. The cylinder was then corked, shaken vigorously and allowed to stand without further disturbance.

Exp. A: 10 grams clay No. 2 (sandy clay), no NaCl. Subsidence very slow. Nov. 28. Height of column 85mm, height of sediment 47mm, supernatant liquid slightly turbid.

A $\frac{1}{2}$: 10 grams No. 2, 0.025 gramme NaCl. Subsidence much more rapid, having been, apparently, completed about Oct. 1st. On Nov. 28, height of column 85mm, sediment 33mm.

A $\frac{3}{4}$: 10 grams No. 2, 0.05 NaCl. Subsidence complete within forty-eight hours. Column 92mm, sediment 33mm, liquid clear and line of demarcation between sediment and liquid sharply defined. A1 and A2, containing 0.1 and 0.2 grams NaCl respectively, showed complete subsidence within 24 hours.

Series B: 10 grams No. 3 (blue clay) taken.

B: No NaCl. Nov. 28. Column 86mm, of which about 5mm could be called clear, the next 10mm, though translucent, was turbid, the rest opaque.

B $\frac{1}{4}$: 0.025 grams NaCl. Nov. 28, column 88mm, sediment 50mm, demarcation fair.

B $\frac{1}{2}$: 0.05 grams NaCl. Nov. 28, column 81mm. Sediment 44mm, demarcation definite, solution clear.

B1: 0.1 gram NaCl. Nov. 28, column 84mm. Sediment 28mm. Sedimentation complete within a week.

B2: 0.2 grams NaCl. Nov. 28, column 87mm, sediment 28mm. Subsidence complete within 48 hours.

Two portions of each clay of 5 grams each with 0.025 and 0.05 gram NaCl, respectively, showed a rate of subsidence much more rapid than that of the corresponding 10 gram portions, and this rate seems to depend upon the salinity of the solution. The further investigation of this subject involves complicated problems in physics, and for practical purposes it is sufficient to know that by the use of small quantities of NaCl the soluble portion of such clays can be easily and completely extracted.

CONCLUSIONS.

The conclusions arrived at in the course of this work may be briefly summarized as follows:

First. Natural soda is formed partly by direct decomposition of rocks through the action of air and water, aided at times by heat and pressure, and partly by subsequent decompositions occurring either in soils or in closed basins. These reactions, especially those of the latter class, are much influenced by the action of organic matter, which not only reduces sulphates, but also, in the form of certain organic acids, has been found to be a powerful reagent in rock decomposition.

Second. Natural soda is, essentially, a definite compound of sodium monocarbonate and bicarbonate, and the other accompanying salts are to be considered only as impurities. The proportion of the two carbonates forming this compound is one molecule of each. Any excess of either carbonate above this ratio is considered to be merely accidental, and the existence of the so-called sesquicarbonate or combination of one molecule of monocarbonate with two molecules of bicarbonate is believed to be very doubtful; at present, the strongest proof of its existence is derived from certain crystallographic determinations.

Third. The mineral urao is the pure form of natural soda, and this compound, having a relation of four-thirds of a molecule of CO_2 to one molecule of Na_2O , may be called the "tetra trita" or "tetritha" carbonate. The sodium carbonates are therefore considered to be but three in number, namely: monocarbonate, tetritha carbonate and bicarbonate.

Fourth. The nature and properties of urao render it the most suitable form in which the natural sodium carbonates can be separated from accompanying salts. Hence any technical method devised for the manufacture of commercial soda from the natural material should be based on the formation and separation of this compound. The method described as being employed at Owen's Lake is, as far as it goes, simple and good, but the yield is not large, when the extent of the plant is considered. Owing to the small proportion of bicarbonate present in the original water, the crop is smaller than could be obtained if the amount of bicarbonate could be increased. Whether this can be economically done can be answered by practical experience only, but the following suggestions may be of value.

As the first step in the purification of a natural soda, it must be dissolved, and the solution should be clear. If such a solution be analyzed it will be found, in most cases, that the proportion of bicarbonate present is insufficient to give the largest practicable yield of urao. The amount of carbonate in the first crop depends upon the amount of bicarbonate in the solution, as this separates first and in separating takes with it a proportionate amount of monocarbonate. We have already seen that a soda ash of very good quality can be made at Owen's

Lake, but the yield under present conditions must be small in proportion to the amount of solution used. If the percentage of bicarbonate could be economically increased, the first crop should be much larger without detriment to its purity, and the increase may be effected either by the direct addition of bicarbonate or by its formation in the solution by causing the latter to absorb carbonic acid under pressure.

If the direct addition of bicarbonate is preferred, advantage may be taken of the fact noticed by Mondesir and others, that if urao is treated with an amount of water insufficient for its complete solution, it is decomposed, Na_2CO_3 going into solution, while NaHCO_3 is left behind. Heat increases the rapidity of the decomposition, but the temperature of the solution should not exceed 37.5°C . (100°F). The NaHCO_3 thus obtained can then be dissolved in the raw solution of the natural soda, which for this purpose must not be too concentrated and, as the bicarbonate dissolves slowly, agitation of the salt with the liquid will hasten this stage of the process.

The solution of Na_2CO_3 obtained by this treatment of a portion of the urao may be utilized by converting it into bicarbonate, using, for this purpose, the carbonic acid given off during the calcining of the soda ash. The proper form of furnace for calcining such material is a continuously working muffle, in which the soda is mechanically fed, stirred and delivered, while the CO_2 is obtained in a pure condition and, when cooled, can be introduced at once into the solution of Na_2CO_3 . For rapid absorption a pressure of about 25 to 30 pounds to the square inch is advisable, hence a pump must be used and the absorbing vessels should be made of light boiler iron. The absorption should not exceed the point at which bicarbonate begins to precipitate, and if the absorbing vessels are properly arranged in a series the carbonating will be a continuous operation and the plant required for quite extensive works will be found to be much smaller than would be supposed. The carbonated solution can be added directly to the raw solution.

If the formation of bicarbonate in the raw solution is preferred, a portion of this may be thoroughly carbonated and then added to the rest. This method has some advantages over the first one, but would probably require a somewhat larger carbonating plant for works of an equal capacity.

While the summer temperature is usually sufficiently high for the proper production of urao, the season is short, under the most favorable circumstances, and the output of works depending entirely upon natural heat correspondingly small. On the other hand, the temperature of the solutions should not be allowed to exceed 100°F . If it be possible to maintain the solution at this temperature during the crystallizing stage, in an economical manner, a great gain would be made, as the works could be run throughout the year, there being, usually, but little difficulty in obtaining and storing up an ample supply of concentrated raw solution. In this direction there is an extensive field for the exercise

of educated ingenuity in the utilization of the waste heat of the calcining furnaces, as also in the economical application of heat derived from fuel burned for this purpose only. The description of the salt works at Pomeroy, Ohio, given in my paper on salt-making processes, in the Seventh Annual Report of the U. S. Geological Survey, shows a most ingenious and exceedingly close utilization of heat derived from fuel of very poor quality, and may give many hints to those desiring to work in this direction.

The utilization of the mother liquor of the first crop is a problem which can only be solved by the growth of this industry. Doubtless in time something can be done with the vast quantities of chlorides and sulphates which are waste products, but their value is too small to give much hope for their utilization under present conditions. The industry is in a preparatory stage only, but will surely become of great importance in the future; the present consumption of sodium carbonate in this country is probably not less than 250,000 tons and is increasing, and a large part of this amount could be supplied by the Great Basin if its resources were utilized. If those who may hereafter take up and prosecute this branch of chemical industry shall find the information given in these pages of value to them, the purpose of this paper will have been realized.



ANALYSES OF SIX NEW METEORITES.

BY J. EDWARD WHITFIELD.

The Rockwood Meteorite.—This meteorite was found about the middle of March, 1887, by Mr. Elihu Humbree on the range of the Cratichard Mountains, in Tennessee. The field in which it was picked is now owned by Mr. W. B. Lenoir, and is situated $8\frac{1}{2}$ miles west of Rockwood, in Cumberland county. The material for analysis was received from Messrs. Ward and Howell, of Rochester, N. Y., the present owners of the meteorite, to whom I am indebted for the privilege of description.



FIG. 5.—The Rockwood Meteorite.

There were three pieces found, the smallest measuring 10cm $\times$ 6cm, and weighing 1.65 kilos; the next larger, measuring 20cm $\times$ 16.4cm $\times$ 6.5cm, and weighing 2.64 kilos; and the largest, an irregular egg-shaped mass, a little flattened on one side, measuring 38cm $\times$ 25.3cm $\times$ 21.5cm, with a weight of about 38.5 kilos and specific gravity of 4.240. An idea of the appearance of this piece can be had from the foregoing cut, which is from a photograph reduced to $\frac{1}{6}$ natural size. The mass is quite brittle, very hard to saw, but easily broken by hammering. Cut slices show many irregularly shaped stony fragments and some nodules, the largest seen being about 1cm on the surface diameter. In the larger slices the stony part is so broken as to give the polished surface a brecciated appearance.

In analysis, the metallic portion was freed from the mineral part by crushing to rather fine particles and separating by the aid of a magnet.

This was again treated in the same manner, and the resulting metal washed with alcohol and quickly dried; by this method it was found possible to free the metal from all but the merest trace of stony substance.

The metallic portion proved to be an alloy, rich in nickel, as is shown by the following figures:

	Per cent.
Fe.....	87.59
Ni.....	12.09
Co.....	trace.
Cu.....	trace.
P.....	none.
S.....	none.
	99.68

The metallic grains seem to be quite evenly distributed through the mass. In but one instance does a nodule appear to have attained a size larger than that of a pea, and on the section of this nodule we were able to obtain the Widmannstätten figure by etching. Cut No. 2 shows the polished slice containing the nodule of natural size:



FIG. 6. Section of Rockwood Meteorite.

The rocky part, after being freed as well as possible from metal, was finely ground and digested with dilute hydrochloric acid, and the resulting soluble and insoluble portions investigated separately, but from the fact of there being a number of minerals mixed together no satisfactory conclusions could be drawn from the examination. The mass was therefore analyzed as a whole with the following results:

	Per cent.
SiO ₂	41.92
Al ₂ O ₃	9.27
FeO.....	22.94
CaO.....	9.09
MgO.....	8.76
Fe.....	3.75
Ni.....	1.74
Cl.....	0.18 = 0.32 FeCl ₃
P.....	0.65
S.....	1.58
	99.88

By the analysis of the portions soluble and insoluble in dilute acid it was found that the greater part of the lime and but a trace of the magnesia had gone into solution, proving the absence of olivine, and giving good grounds for the supposition that the rocky portion is mainly a mixture of anorthite and a silicate related to augite, but very rich in iron. It will be noticed that the ratio between the iron and nickel in the metallic portion is greater than that in the rock. This is accounted for by the fact that in the rocky part of the meteorite the iron, as metal, has been greatly oxidized, as is shown by the large amount of rust covering the specimen, caused no doubt by the chloride of iron present, and is reckoned as FeO, accounting for the large proportion of iron in the supposed augite.

Owing to the bad condition of the fragments subjected to analysis we have no grounds on which to compute the phosphorus and sulphur as schreibersite and troilite, but from the fact of these minerals being among the more common constituents of this class of meteorite, and also that in the main analysis of the rock portion phosphorus and sulphur were found, it is probable that the phosphide and sulphide of iron are two of the minerals present.

One of the polished slices contained a small nodule, which was sacrificed in order that its nature might be determined, and the following figures give the results of analysis. The mineral was finely ground, the metallic portion, if any, separated by aid of the magnet, and the residue was digested in dilute hydrochloric acid.

The insoluble portion was found to be 94 per cent., the composition of which is

	Per cent.
SiO ₂	51.85
Al ₂ O ₃	4.52
FeO	13.26
CaO	1.09
MgO	29.28
	100.00

This gives the ratio of R''O to SiO₂ = .93 : .86, which corresponds well with the mineral eustatite, although in this case much of the magnesia is replaced by iron. The soluble portion consisted of iron with a slight trace of nickel, which tends to show that the nodule contained some metallic particles which it was impossible to extract with the magnet. During the digestion in acid, as no sulphuretted hydrogen could be detected, we infer the non-existence of sulphides in the nodule.

The total mineral was also analyzed with the following results:

	Per cent.
SiO ₂	49.96
Al ₂ O ₃	4.75
FeO	15.97
CoO + NiO	trace.
CaO	1.15
MgO	28.15
	99.98

This meteorite, then, is a lithosiderite, poor in metal, the metallic portion not exceeding 16 per cent. of the mass. The stony part is probably anorthite and enstatite.

Chattooga County Meteorite.—This mass of meteoric iron was found by Mr. W. J. Fox, about the 27th of March, 1887, on his farm near Boland's Store, Chattooga county, Ga. In all 12.5 kilos were found, but the mass was rather roughly handled, being broken into pieces and some of them worked into horseshoes and nails by the local blacksmiths. Three of the fragments were obtained by Mr. G. F. Kunz, of New York city, and described by him in the December, 1887, number of the American Journal of Science.

The material received from Mr. Kunz for analysis gave the following results:

	Per cent.
Fe.....	94.60
Ni.....	4.97
Co.....	.21
P.....	.21
Cl }	traces.
Ss }	
	99.99
Specific gravity.....	7.801

Taney County Meteorite.—We received from Mr. George F. Kunz, the present owner of this meteorite, the material for analysis. The description has been fully given by him in the December, 1887, number of the Am. Journal of Science.

This being one of the class termed stony meteorites, a number of analyses were made on the rocky portion, in order, if possible, to ascertain the character of the minerals present.

The analysis of the metallic part is as follows:

	Per cent.
Fe.....	89.41
Ni.....	10.41
Co.....	.29
P.....	.16
	100.27

Of the rock material separated from metallic grains the analysis gave

	Per cent.
SiO ₂	45.88
Al ₂ O ₃	7.89
FeO.....	19.73
CaO.....	6.02
MgO.....	17.96
NiS.....	1.67
FeS.....	.54
	99.69

The fragment as received gave a specific gravity of 4.484. As far as I can judge the insoluble mineral of the rocky portion is enstatite, and the soluble part a lime-iron silicate with considerable Al₂O₃. Of the

portion insoluble in dilute hydrochloric acid the following figures are the results of analysis:

SiO ₂	52.39 = .87	
Al ₂ O ₃	7.11	
FeO.....	14.68	.20
CaO.....	4.49	.08
MgO.....	21.33	.53
	<u>100.00</u>	

Ratio of SiO₂ : R''O = .87 : .81 which agrees pretty well with enstatite; but here the MgO is replaced by much FeO, and the presence of Al₂O₃ makes the ratio vary a little from the normal 1 : 1. Deducting all the S as NiS and the Fe to correspond to the remaining S from the soluble part, we have for the percentage of the soluble part:

	Per cent.
SiO ₂	26.95
Al ₂ O ₃	17.69
FeO.....	35.98
CaO.....	15.98
MgO.....	3.40
	<u>100.00</u>

The little MgO here probably comes from the slight solubility of the enstatite in the hydrochloric acid.

This meteorite is similar to the so-called Newton county, Ark., stone described by Dr. J. L. Smith,¹ and Mr. Kunz has found that the mass originally fell in Taney county, Mo., but that a fragment was broken off and taken to Newton county, Ark.

Linnville Mountain Meteorite.—About the year 1882 a mass of meteoric iron was found on Linnville Mountain, Burke county, N. C. Eventually it came into the hands of Mr. Kunz and was described by him in the American Journal of Science.²

Material for analysis was furnished by Mr. Kunz and gave the following results:

	Per cent.
Fe.....	84.56
Ni.....	14.95
Co.....	.33
Cu.....	none.
S.....	.12
C.....	trace.
P.....	trace.
	<u>99.96</u>

The Fayette County Meteorite.—The meteorite described below was found some ten years ago at Bluff, a settlement on the Colorado River about three miles southwest of the town of La Grange, in Fayette county, Tex. Bluff can not boast of being a village, as it is simply made up of a few farms scattered within a radius of two miles. The farmers are

¹ *Am. Jour. Science*, vol. 40, 1865.

² *Ibid.*, vol. 36, Oct., 1888.

mostly Germans or Bohemians, and as they are generally of the superstitious class, it is not strange that the finder, a Bohemian, named Raniosek, should have been struck by the appearance of the stone, and especially by its weight. As it is probable that he never heard of such a thing as a meteorite, it is safe to say that he did not know the nature of his find; still he seems to have come to the conclusion that it was something foreign to the soil.

There is a tradition in Fayette county that Santa Aña, at the time of his flight after the battle of San Jacinto, buried his war treasures somewhere near La Grange, and the belief has so fixed itself in the minds of the inhabitants that many fruitless attempts have been made to discover them. The finder of the meteorite, with the tradition fresh in his mind, reasoned that so large and heavy a stone must mark the place where some treasure was deposited; he therefore rolled the stone a few feet aside and dug a deep hole at the exact spot where the stone had been, without finding anything to pay him for his labor.

For several years the stone lay where the Bohemian had left it; then he sold the piece of land to Mr. C. Hensel, who still owns it; but before the latter had taken possession Raniosek removed the stone to his own farm, about a mile away, where for five years more it lay neglected in his yard. His reason for removing it was that its weight led him to suspect it contained some valuable metal.

About three years ago Mr. H. Hensoldt took charge of the school at Cedar, two and one-half miles from Bluff settlement. While spending his time in hunting for fossils, minerals, etc., the attention of the farmers was drawn to him, and in January, 1888, he was informed of the strange stone in Mr. Raniosek's yard. Immediately on seeing it he recognized it as a meteorite, and a very fine specimen of its kind.

After obtaining possession of the stone Mr. Hensoldt disposed of it to Messrs. Ward and Howell, of Rochester, N. Y., to whom we are indebted for the material for study and the privilege of description. On receiving the stone Mr. Howell published a notice in *Science* (February 3, 1888, p. 55) putting it on record as the "LaGrange Meteorite," but on finding that this name had already been applied to the Oldham County, Ky., Meteorite, agreed that it should be called the Fayette County Meteorite.

The stone possesses all the characteristics of a meteorite. The pittings are well marked, but the crust shows only in the deeper depressions; a freshly fractured surface shows, besides the grains of metal, a greenish-gray appearance not unlike some greenstones. A particularly interesting feature of the stone is the presence of a few dark-colored veins varying greatly in dimensions—the one in the specimen for examination being some 2mm in the greatest width and 60mm in length.

The three dimensions of the mass are 58cm $\times$ 46cm $\times$ 28cm, and the total weight about 146 kilos. A good idea of the appearance of the meteorite may be had from figure 7.

Before the specimen was pulverized for analysis the vein was care-

ly sawed out, so as to keep all the vein material from the mass. The
ck was then ground as fine as possible, and a portion (1 gram) treated
ith iodine in cold water, to separate the metallic particles. The residue

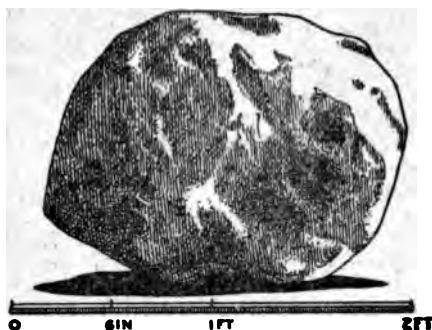


FIG. 7.—The Fayette County Meteorite.

as filtered on a Gooch soluble filter and washed free from iodine. The
cky material, after being weighed, was treated with dilute hydrochloric
acid and allowed to stand for some time, then filtered, and the residue
weighed; in both cases the mineral being separated from the filter by
using the proper solvent for the anthracene—washed with ether and
alcohol and dried at 100° C. This temperature was not sufficient to
drive all the water from the mineral part, which accounts for the discrep-
ancy of about 2 per cent.

The following figures will show the composition of the metal and the
rock, soluble and insoluble, in hydrochloric acid; also the results of a
complete analysis of the total mass:

	No. 1.	No. 2.	No. 3.	No. 4.
	Total mass.	5.67 per cent. of total (metal).	33.3 per cent. of total (in- soluble in HCl).	60.62 per cent. of total (soluble in HCl).
SiO ₂	37.70		49.64	33.59
Fe	3.47	82.42		
FeO	23.82		15.56	31.12
Al ₂ O ₃	2.17		4.12	1.34
P ₂ O ₅	.25			.42
CaO	2.20		4.93	1.00
MnO	.45		.54	.43
MgO	25.94		25.21	28.08
NiO	1.59		trace.	2.66
Ni	.65	15.44	trace.	
CoO	.16		trace.	.27
Co	.09	2.14		
S	1.30			2.18
	99.79	100.00	100.00	101.09
Less O for S	.65			1.09
	99.14			100.00
Specific gravity	3.510			

The percentages in all except the first are calculated from the weight
found.

From these figures it will be seen that the minerals which go to make up the rocky portion of the meteorite are essentially olivine and enstatite, with considerable pyrrhotite, as is also shown by the microscopical description, for which I am indebted to Mr. G. P. Merrill, of the U. S. National Museum, by whom the paper was published in the *American Journal of Science*.¹

The stone belongs to the class of meteorites to which G. Rose² has given the name "chondrites." To the unaided eye the chondritic structure is not distinctly marked, a broken surface showing a fine-grained and evidently crystalline granular rock, very compact, of a greenish-gray color, and thickly studded with small metallic points with a brassy luster. A polished surface shows the stone to be composed of small chondri rarely over 2mm in diameter, thickly and firmly compacted in a fine granular groundmass. Throughout the entire mass are thickly distributed innumerable small irregular flecks of a steel-gray, brassy, and bronze-yellow color, presumably native iron and pyrrhotite.

The striking feature of the stone is its fine and compact texture, which exceeds that of any chondritic meteorite with which we are acquainted, but which is perhaps most closely approached by the stones of Dharmasala, India, and Cabarrus county, N. C.

Thin sections of the stone show, under the microscope, a confused aggregate of rounded and irregular, often fragmental, olivine and enstatite grains and chondri, embedded in a fine granular groundmass of the same mineral composition.

The chondri occur in both monosomatic and polysomatic forms composed either of olivine or enstatite alone or the two minerals associated. The peculiar grate-like or barred forms so characteristic of olivine chondri are here represented, as are the radiating fan-shaped forms of enstatite.

The large greenish microscopic chondri are, under the microscope, seen to be made up of innumerable enstatite granules so arranged as to form oval or fan-shaped areas of radiating columns, inclosing large, quite perfectly outlined, crystals of the same mineral. These included forms are nearly colorless or merely gray through inclosures of innumerable dust-like particles, and show sharp and well-defined cleavages parallel to either prism and a parting parallel to the orthopinacoid. Both olivine and enstatite are nearly colorless or gray through inclosures of dust-like particles, and carry but few cavities.

In addition to the minerals above mentioned there were noticed occasional broad, irregular plates of a monoclinic mineral, light gray in color, but polarizing brilliantly in red and yellow colors, and which gave extinction angles varying from 25° to 31° . Such are presumably augite or a closely allied pyroxene. Nothing that can be certainly identified as a feldspar was observed. Occasional small nearly colorless angular forms show faint indications of twin structure, and it is possible may

¹ Whitfield & Merrill: *Am. Jour. of Science*, vol. 36, Aug. 1888.

² *Abhandl. der königl. Akad. d. Wissensch. zu Berlin*, 1863, p. 1861.

be a plagioclase. In two sections were observed irregular outlin
terstitial areas perfectly colorless and full of gas cavities. Th
some cases remained quite dark during a complete revolution o
stage, and in others gave decided polarization in light and dark
and in converging light showed indistinct biaxial interference fi
The position of these areas relative to the other constituents is t
an interstitial glass or a secondary mineral like a zeolite. As
show neither cleavage nor crystallographic outlines, and moreov
to be found but rarely in the sections at hand, it is impossible to
tify them satisfactorily.

The metallic iron occurs in the usual rounded and irregular n
one to two millimeters in diameter, and is apparently in about
proportions with the pyrrhotite: the latter showing a bright l
luster in strong contrast with the
silvery white iron.

The black vein above noted trav
erses the stone in the form of an
irregular fissure (often expanding
and contracting abruptly, as is
shown in Fig. 8), for a distance of
about 60mm, and varies in width from a mere line up to 2mm.
its lower end it bifurcates, and incloses a portion of the mass
meteorite some 15mm long by 2mm wide.¹

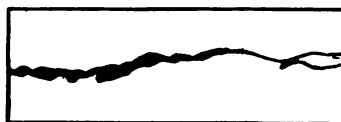


FIG. 8.—Vein in Fayette County Meteorite.
Natural size.

From a fragment containing a portion of the vein thin sections
prepared, and the remaining vein material, separated as clearly a
sible from the inclosing rock, was subjected to chemical analysi
process being essentially the same as in the analysis of the met
proper. Although the vein material is more compact and much d
in color, the analysis shows very little difference from that of the
the main apparent difference being the absence of the lime be
mineral. The following are the figures obtained by analysis on
rial that weighed a little less than 0.4 grams:

	Metal.		44 per cent. of vein. Insoluble in HCl.	51 per cent. of vein. Soluble in HCl.
Fe	2.30	SiO ₂	56.52	27.63
NiCo	traco.	FeO	12.35	34.31
		Al ₂ O ₃	1.51	2.41
		CaO	trace.	trace.
		MgO	25.53	32.12
		(NiCo) O	4.09	3.27
		S		.52
			100.00	100.26
		Less O for S		.26
Specific gravity ..	3.585			100.00

¹ Since the above was written Messrs. Ward and Howell have sliced th
through the center and published in Science of June 1, 1888, a figure show
full extent and width of the veins

The same difficulty, with regard to water in the mineral, exists here as in the analysis of the mass.

From the figures it appears that the portion soluble in hydrochloric acid is essentially olivine in composition, while the insoluble is evidently a mixture of the same insoluble constituents as the mass of the meteorite. The filling material of the vein is, to the unaided eye, quite black and without luster; under the microscope it is seen to penetrate very irregularly and by innumerable minute vein-like ramifications into the stony mass on either side, and to carry numerous inclosures of a colorless mineral substance and blebs of metallic iron and pyrrhotite. The exact nature of the colorless inclosures can not be ascertained. On treating an uncovered slide with hydrochloric acid a part of these were dissolved, others were unacted upon. Under the microscope they are full of irregular rifts and fracture lines, but show no true cleavages. Some of them are in the form of single individuals, others have the structure of fragments of polysomatic chondri. Nearly all contain included black amorphous material, and many show distinctly included specks, giving the silvery white and brassy yellow reflections of the metallic iron and pyrrhotite. In many cases they are not separated from the black vein material by sharp lines, but seem to pass into it by gradations. Between crossed nicols many of them act like a gum, others remain always light, recalling the well-known crypto-crystalline structure of chalcedony, and still show here and there occasional small areas giving the characteristic polarization colors of olivine and enstatite. On examining the walls of the vein areas were observed where the gray and yellowish enstatites and olivines retained their normal properties at the distance of one or two millimeters, but at contact with the black-vein matter were reduced to the colorless non-polarizing condition of the inclosures.

The black matter of the vein when viewed in strong reflected light shows a dull bronze luster, less brilliant than that of the pyrrhotite particles which it incloses. The thinnest portions of the slide when examined with a power of 175 diameters show a brownish amorphous base through which are scattered abundant irregular dust-like particles and flecks of a perfectly black opaque material, the nature of which it is impossible to ascertain by the microscope alone.

The structure of the vein is shown in figure 9, in which the finely dotted portions represent the black amorphous vein matter with bronzy luster, the entirely black areas, the blebs of metal and pyrrhotite, and the irregularly rounded clear or partly clouded areas the colorless silicates.

From the study of these veins as above described we are inclined to consider the colorless particles as olivine and enstatite residuals which have been deprived of their normal optical properties by the forces active in forming the vein. What the exact character of the black and amorphous material may be still remains a matter of conjecture. It

nacted upon by acids, and when tested with a needle point it breaks readily into earthy fragments which are not attracted by the magnet. Mr. Howell informs me that the specimen in his possession shows three of these veins, the largest exposure being only one on a broken surface being not over four inches. The width and general character of all, he states, appear to be uniform throughout, although this can be ascertained definitely only by breaking the stone.¹

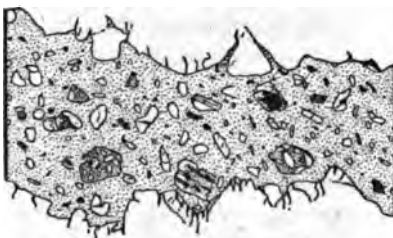


FIG. 9.—Portion of vein highly magnified.

owing to the small amount of vein material which was available for chemical analysis and the impossibility of separating it completely from the inclosing rock, the results obtained must be regarded only as suggestive. The main points brought out can best be shown by reproducing here a comparison of the results:

	Mass of meteorite.	Vein material.
SiO ₂	37.70	38.96
Fe	4.41	2.30
FeO	23.82	22.98
Al ₂ O ₃	2.17	1.80
CaO	2.20	trace.
MnO	.45	.....
MgO	25.94	27.52
Ni, Co	1.75	3.26
S	1.30	.26
Specific gravity	3.510	3.585

In structure these veins seem to only remotely resemble those described by Tschermak (Sitz. der kais. Akad. der Wiss., vol. 85, Part 1, p. 204) in the Mocs meteorite, which, it will be remembered, he argued indicated an elevation of temperature at the consolidation of the stone, such as, aided by reducing vapors and gases, fused iron and pyrrhotite without affecting the silicates. He describes the brown and black "Fullmasse" of the vein as an admixture of the same substance as the meteorite itself, and an opaque half glassy black admixture resembling the black vein material of the Orvinio stone. The silicates occur in the vein in the form of sharp splinters, the iron in granules, and the pyrrhotite in the form of little plates and small kernels, often so arranged as to give rise to a fluidal structure. Dr. Rensch has described (N. Jahrb. für Min., iv Beil.-Band, 3 Heft, 1886, pp. 491-492) veins in the Ståldalen meteorite which present features in part common to those of the Fayette stone. To the unaided eye the filling material is black and opaque and carries metallic particles. Under the microscope it shows a brownish gray, isocratic and sometimes glassy substance densely crowded with rounded transparent inclusions. The upper figure in his Plate XIV closely resembles in structure the matter of the Fayette stone, but as far as can be judged from his description the included particles seem to have retained their normal optical properties. Rensch describes this black vein material as the result of a partial refusion of the chondritic matrix.

These differences are too slight to be considered of great value unless found to be constant by further investigation.

San Bernardino County Meteorite.—A prospector working in the San Emigdio Mountains, California, found this meteorite, and thinking it to be a lump of some valuable ore sent it to Mr. Thomas Price, of San Francisco, for assay. Unfortunately before the nature of the sample was discovered it was put through a crusher and hence only small pieces could be obtained. On finding that it was a meteorite, Mr. Price sent a few fragments to Mr. G. P. Merrill, of the U. S. National Museum, for investigation. Mr. Merrill has published a note on the subject in the June, 1888, number of the American Journal of Science, and later a full description in Vol. 11 of the Proceedings of the National Museum.

From Mr. Merrill we received material for analysis, but the bad condition of the fragments made a complete analysis almost impossible.

The mass consists of

	Per cent.
Metallic portion.....	6.21
Soluble in HCl.....	51.26
Insoluble in HCl.....	42.23

Of this the metallic portion gave as its composition—

	Per cent.
Fe.....	88.25
Ni.....	11.27
Co.....	.48

The soluble portion is presumably all olivine and pyrrhotite, with some secondary iron oxide. The analysis of this portion by separation with dilute hydrochloric acid was a failure. The insoluble part was separated by long digestion in dilute acid followed by boiling in sodium carbonate. The remaining powder showed, with the aid of the microscope, the presence of very pure enstatite and very little else, and the chemical composition upholds this view.

	Per cent.
SiO ₂	54.42
FeO.....	14.03
CaO.....	2.46
MgO.....	29.11
	100.02

From these figures it will be seen that the mineral is a highly ferri-ferous enstatite (bronzite) with a small amount of a lime-bearing pyroxene mineral. The relative proportions of the various constituents as they exist in the first rock can not be estimated with any degree of certainty for the reasons already stated.

TWO SULPHANTIMONITES FROM COLORADO.

By L. G. EAKINS.

The mineral first to be described was sent to the Denver laboratory of the U. S. Geological Survey in the latter part of 1885 by Mr. E. R. Warren, of Crested Butte, Colo.

At that time a hasty qualitative examination was made, establishing the fact that it was a sulphantimonite of lead, and since then nothing more has been done with it until the present analysis was made.

This mineral comes from the "Domingo" mine, on the ridge between Dark Cañon and Baxter Basin, Gunnison county, Colo., in which locality it is known as "mineral wool." It consists of aggregates of small acicular crystals, forming matted, wool-like masses in the cavities of a highly decomposed gangue rock of siliceous material mixed with some calcite. It is dull grayish-black in color, with occasional spots of iridescence, due undoubtedly to a slight superficial oxidation.

In procuring material for analysis a lot of loose material sent by Mr. Warren was slightly crushed and rubbed with water in a mortar and poured off, the fine needle-like crystals floating off readily; this was afterward purified by a retreatment in the same manner, and then subjected for a short time to the action of dilute hydrochloric acid to remove the slight amount of attached calcite. The material obtained in this manner appeared under the microscope to be perfectly pure and homogeneous, with the exception of a slight amount of gangue still remaining.

No crystalline form could be made out, and on account of its peculiar nature no attempt has been made to determine either specific gravity or hardness. Heated before the blow-pipe it fuses readily without decrepitation; in the closed tube it gives a slight sublimate of sulphur only; in the open tube it gives off sulphurous acid and dense white fumes of oxide of antimony; heated strongly the antimony all volatilizes, leaving a fused residue of sulphate of lead, slightly colored by the iron present; on charcoal it gives the lead and antimony coatings, and in the reducing flame with soda a lead button. It is soluble in hot *strong hydrochloric acid* with evolution of hydrogen sulphide.

The analysis is as follows:

	Atomic ratios.
Ag	trace.
Cu	trace.
Pb	$39.33 \div 207 = .190$
Fe	$1.77 \div 56 = .032$
Mn	trace.
Sb	$36.34 \div 120 = .303$
S	$21.19 \div 32 = .662$
Insoluble gangue	.52
	99.15

Dividing these atomic ratios by .222, we get:

Pb, Fe	1.00	= 3.00
Sb	1.36	4.08
S	2.98	8.94

Giving the formula: $(\text{Pb, Fe})_3\text{Sb}_4\text{S}_9$, or $3(\text{Pb, Fe})\text{S}, 2\text{Sb}_2\text{S}_3$.

This mineral, it is seen, fills a place in the group, $3\text{RS}, 2(\text{As, Bi, Sb})_2\text{S}_7$, of which there are but few good examples, and which until now has not had an antimony representative.

The somewhat low summation of the analysis is probably due to two causes: First, a small amount of soluble gangue which was present and undetermined; second, the sulphur is about four-tenths of one per cent. less than required, due to the slight natural oxidation of the mineral together with an additional amount induced by treatment with dilute hydrochloric acid for the removal of calcite. In addition to the complete analysis given, there were additional determinations made of lead, antimony, and sulphur, the results obtained being in strict agreement with those given above.

The second of these sulphantimonites was collected in the summer of 1887, by Mr. Whitman Cross. It comes from a mine on Augusta Mountain, Gunnison county, Colo., this locality being about one mile east of the "Domingo" mine. Locally this mineral is also known as "mineral wool," and although differing considerably in appearance from the one just described, they were, on account of the similarity of occurrence, considered as probably identical.

It occurs in a siliceous gangue together with pyrite and sphalerite and forms groups of acicular crystals, which are elongated prisms deeply striated, but whose form could not be determined.

The individual crystals of this mineral are considerably larger than those of the one previously described, and in consequence they do not tend so much to form matted aggregates. Its color is a bright, steely grayish-black, with no tendency toward tarnish or iridescence. The separation of this mineral from the accompanying ones and the gangue was a matter of considerable difficulty. On account of their size the crystal could not be successfully washed out from the other material, but by the use of a rapid current of water and the Thoulet method a small quantity was finally procured perfectly free from everything except

some pyrite, and that had no effect upon the analysis, as the was dissolved in a mixture of hydrochloric and tartaric acids, the pyrite unattacked. It was then filtered through a Gooch and the amount of pyrite determined and deducted from the taken. The fact that but a trace of iron was found in the and conclusive proof that the pyrite was practically unattacked.

Blow-pipe characteristics are the same as in the one before de
The analysis is as follows :

	Atomic ratios.
Ag.....	trace.
Pb.....	55.52 ÷ 207 = .26
Fe.....	trace.
Sb.....	25.99 ÷ 120 = .21
S, (calculated).....	18.98 ÷ 32 = .59
	100.49

Dividing these atomic ratios by .217 we get:

Pb	1.24 = 4.9
Sb.....	1.00 4.0
S	2.74 10.9

Giving the formula :— $\text{Pb}_5\text{Sb}_4\text{S}_{11}$ or $5\text{PbS}, 2\text{Sb}_2\text{S}_3$.

We have here, in formula, a freieslebenite in which instead and silver the silver has been completely replaced by lead, and a the crystallographic agreement of this mineral with freiesleben not been established, there seems to be no good reason for not r it to that species. The first described of the above minerals Fe) S, 2 Sb, S₃, has been given the name "Warrenite," after the man who brought it to our notice. The same mineral has been nated "domingite" by Groth.



COEFFICIENTS OF VOLATILITY FOR AQUEOUS CHLORHYDRIC ACID.

By ROBERT B. WARDER.

The various questions of physical chemistry are claiming more and more attention, and problems relating to states of aggregation seem to have a special interest. The art of fractional distillation on a manufacturing scale has developed a great variety of appliances, but much remains to place the theory on a satisfactory mathematical basis, especially in the case of bodies which exert a mutual affinity.

The term "coefficient of volatility" was introduced by Wanklyn¹ to indicate the relative readiness of different constituents to volatilize. Thus he found that when a very dilute solution of ammonia was distilled until $\frac{1}{10}$ of the water passed over, nearly $\frac{1}{2}$ of the ammonia had distilled with it. He estimated that a given quantity of water in any small fraction of the distillate was accompanied by 13 to 14 times as much ammonia as the same quantity of water in the boiling liquid. Expressed more formally, if a boiling liquid has the composition $H_2O + nNH_3$, and yields a mixed vapor represented by $H_2O + vnNH_3$, the factor v is the coefficient of volatility, and in the case cited v equals about 13 or 14. Since this gas may be absorbed in indefinite proportions, of course the coefficients n and vn may be fractional, indicating the number of molecules of NH_3 divided by the number of molecules of H_2O .

In the case of chlorhydric acid, as is well known, when the liquid boils under the ordinary atmospheric pressure, it tends to acquire the constant composition $HCl + 8H_2O$, or $H_2O + \frac{1}{8}HCl$. After a stronger or weaker acid has reached this composition, on further boiling $n=vn$ and the factor v =unity.

The well known researches of Roscoe and Dittmar² showed that an acid of higher composition will boil unchanged under diminished pressure; a similar result was observed upon evaporation in a current of air of given temperature to supplement the partial pressure exerted by acid and aqueous vapor. Hence it is clear that v depends not only upon the composition of the mixture, but also upon the pressure (or temperature) at which the distillation is conducted. The published

¹ Philos. Magazine, [4] 45, 129 (1873). Pharm. J. Trans., [3] 3, 543 (1873).

² Jour. Chem. Soc., 12, 128.

data relate to the conditions under which $v=1$, but no attempt has yet been made to show the relation between v and n .

The more recent researches of Roozeboom show certain conditions of equilibrium among solid, liquid, and gaseous phases of aqueous chlorhydric acid¹ and other compounds which are illustrated by thermodynamical theory;² but the papers do not discuss the ordinary conditions of distillation.

Many operations of manufacturing, geological, and analytical chemistry depend upon the partial or complete separation of volatile constituents. Chlorhydric acid is typical of a large number of substances which have strong attraction for the solvent; and a more exact knowledge of its *volatility* as a function of the *composition* is the object of this research.

EXPERIMENTAL METHOD.

One hundred cubic centimeters of chlorhydric acid of known strength was subjected to fractional distillation in a boiling flask of 250cm³ capacity. Successive portions of the distillate were conducted through a Liebig condenser and discharged near the bottom of receivers; a loosely fitting cork was used to hinder evaporation. The several fractions, after weighing in well stoppered vessels, were titrated with sodium hydrate, containing a little barium hydrate and carefully protected from the air by soda lime. Phenol phthalein was used as indicator. In some cases very weak distillates were evaporated with excess of ammonia, and titrated with centinormal silver solution and potassium chromate. The water was determined by deducting the acid from the total weight of the fraction. As a rule no reliance was placed upon specific gravity, the ordinary summer temperature of the room being far above that recognized in the tables; hence the acid used for each distillation was weighed. The residues in the boiling flask were also weighed and titrated for control.

When fractional distillation is conducted for the purpose of separating the constituents, this is promoted by some kind of dephlegmation; this may be accomplished by exceedingly simple means, as the walls of an ordinary boiling flask, by the complicated appliances of the manufacturers, or by the many devices for laboratory use. The object of the present work required the exclusion of dephlegmation, since this would introduce an element of great uncertainty. The flask was placed in a cylindrical air bath and covered with a conical hood of sheet copper. By means of a ring burner (as devised by Gibbs), with very gentle air blast, a circle of gas jets was thrown upon the copper cone, so as to keep the upper part of the flask heated far above the boiling point

¹ Rec. Trav. Chim. Pays-Bas, 3, 84 (1884). Abstract in Zeitsch. physik. Chem., 1, 365 (1887) and 2, 459, (1888).

² Rec. Trav. Chim. Pays-Bas, 5, 335 (1886). Abstract in Zeitsch. physik. Chem., 2, 409 (1888).

fluid, while distillation was effected by a large Bunsen burner the air bath. A thermometer in the vapor was usually kept at a temperature of 145° to 153° . The boiling point of the liquid was from 109° C. (varying with the concentration); and from the rate of evaporation and the space above the liquid, it was estimated that the vapor would pass from the surface to the condenser in about six seconds; it is not to be supposed that the thermometer indicated the actual temperature of the vapor, but something between this and the temperature of the radiating surface of glass or copper. By this means the condensation of moisture upon the sides of the flask was prevented. A preliminary experiment with $\text{H}_2\text{O} + .037\text{HCl}$, the first fifty per cent. distilled without the hood and ring burner contained no more acid than the first per cent. distilled with the precaution described; and this was one-twentieth as much acid as distilled in the first 50 per cent. from the heated cover.

When the distillation proceeded, and the volume of vapor increased, the temperature had to be moderated by turning down the flame.

At the distillation of strong acid each receiver was weighed with 10cm^3 of water to absorb the acid fumes.

CALCULATION OF RESULTS.

The weight of HCl found in each fraction of the distillate subtracted from the total weight, leaves the weight of water; and the weights of water and acid thus found in each fraction were subtracted successively from the water and acid taken to find the composition after the removal of this fraction. The mean composition of the boiling liquid after the removal of each fraction was expressed in the form $\text{H}_2\text{O} + n\text{HCl}$, the composition of the distillate being $\text{H}_2\text{O} + n'\text{HCl}$ or $\text{H}_2\text{O} + v\text{HCl}$. The coefficient v was then found by dividing n' by n . Four calculations gave 25 pairs of values as follows:

I.		II.		III.		IV.	
n	v	n	v	n	v	n	v
.0952	.284	.0681	.140	.0666	.084	.1939	5.44
.1031	.423	.0759	.194	.0693	.111	.1853	3.71
.1107	.537	.0862	.282	.0730	.158	.1713	2.40
.1186	.645	.0984	.429	.0769	.172	.1567	1.66
.1231	.868	.1107	.597	.0806	.198	.1474	1.31
				.0844	.243		
				.0879	.247		
				.0911	.253		
				.0944	.300		
				.0970	.311		

DISCUSSION OF RESULTS.

Two points remain to be considered :

First. What formula will best express the values found for v as function of n ?

Second. Do the relations here determined point to actual equilibrium between liquid and vapor ?

No one equation was found to express all the values given above. When dilute acid ($n=.07$ to $.11$) was boiled rapidly (about one gram per minute) the results agreed with the equation

$$v=445n^3,$$

as in series II. When strong acid ($n=.15$ to $.20$) was boiled rapidly, the values of v were somewhat greater than would be indicated by the equation above; approximately,

$$v=3063n^4,$$

as in series IV. These two empirical curves, which occupy different parts of the field, are entirely consistent with each other, but must be regarded as a *first approximation only* to the function sought. When the dilute acid of Series I and III was boiled from 20 to 60 per cent. more slowly than that of Series II, the values of v were about 10 to 30 per cent. less than those indicated by the equation. There can be little doubt that v is a function of the rate of boiling as well as of the composition of the liquid. The problem appears to be dynamical, not a question of equilibrium merely, and I hope to investigate this point further.

ANALYSES OF JADE.

By F. W. CLARKE.

In the ethnological collections of the U. S. National Museum there are many objects of jadeite, nephrite, and various jade-like stones. They represent a wide range of localities, especially as regards the North American specimens, and in their external characteristics they exhibit great variety of color, texture, and quality. Some came from regions which have already been well studied, but others, as in the series of articles from Alaska and Costa Rica, seemed to merit further investigation. At the earnest desire of the late Professor Baird, their mineralogical description was undertaken by Mr. G. P. Merrill and myself, and our joint paper, giving my analyses and his microscopic examinations, has already been published by the National Museum.¹ The present communication contains merely my own portion of the work, as part of the year's record of the chemical laboratory.

In Alaskan specimens of jade the museum is particularly rich. Since the acquisition of that territory by the United States it has been visited by many official expeditions, and their assembled collections represent the entire coast-line from Point Barrow to the southernmost extremity. If we except the remarkable hammers of jade-like pectolite described by me some years ago,² all of the Alaskan jades are true nephrites, undistinguishable in most particulars from the nephrites of Siberia, New Zealand, or the Swiss Lake Dwellings. In general this nephrite is coarse in quality; but occasionally objects are seen having high finish, some translucency, and great beauty. The following worked specimens were examined, the material for analysis being in each case carefully sawed off to avoid unnecessary damage to the object.

- A. Part of a small adze, Cape Prince of Wales. Yellowish-green, mottled. Specific gravity 2.989.
- B. Material for a drill, St. Michael's. Siskin green, translucent, uniform in texture. Specific gravity 3.006.
- C. Small knife, Diomedé Island. Blackish-green, mottled and laminated. Specific gravity 3.010.
- D. Adze, Point Barrow. Nearly black superficially, opaque. Specific gravity 2.922.

¹ Proc. U. S. National Museum, 1888.

² Bull. U. S. Geological Survey, No. 9, p. 9.

The specific gravity determinations were made by Dr. William Hallock. The analyses, by myself, were as follows:

	A.	B.	C.	D.
Ignition	1.91	1.42	2.03	2.06
SiO ₂	56.01	56.12	56.08	57.11
Al ₂ O ₃	1.98	.63	1.01	2.57
FeO	6.34	7.45	7.67	5.15
MnO	trace.	trace.	trace.	trace.
CaO	12.54	12.72	13.35	11.54
MgO	21.57	20.92	19.96	21.38
	106.35	99.26	100.10	99.81

In each case the ferrous oxide represents the *total* iron. Ferric oxide was not discriminated, nor were alkalies looked for. So far the analyses are incomplete.

In addition to the above-named implements, another object of supposed jade was examined. It was a flaker from Point Barrow, of a dull bluish-green color, conchoidal fracture, considerable translucency, and specific gravity 2.654. These data, together with a partial analysis, identify the object as quartz. It contained 97.79 per cent. of silica.

Concerning the origin of the Alaskan jades there has been much discussion. Some early writers ascribed it to Siberian sources, but of late years evidence has been gathered pointing to a home locality. Native reports indicated a source known as the "Jade Mountain," which lies north of the Kowak River about 150 miles above its mouth, and after several efforts the spot has been actually visited by Lieut. G. M. Stoney. He collected specimens of jade *in situ*, and a number of specimens were submitted to me for analysis. They may be described as follows:

- A. Greenish-gray, splintery-lamellar in structure.
- B. Like A, but more granular.
- C. Paler, nearly white, closer grained.
- D. Brownish, highly foliated.

All four were analyzed with the subjoined results:

	A.	B.	C.	D.
Ignition	1.78	1.38	1.76	1.73
SiO ₂	58.11	55.87	56.85	57.38
Al ₂ O ₃	.24	2.07	.88	.19
Fe ₂ O ₃	5.44	5.79	4.33	4.43
FeO	.38	.38	1.45	1.25
MnO	trace.	trace.	trace.	trace.
CaO	12.01	12.43	13.09	12.14
MgO	21.97	21.62	21.56	22.71
	99.93	99.54	99.92	99.83

If we connect this evidence with the microscopic evidence obtained by Mr. Merrill, it becomes clear that all the Alaskan jades are essentially identical, varying among themselves no more than specimens commonly vary from a single locality. This disposes of the theory that their presence in Alaska is to be accounted for upon the basis of trade with Siberia; which theory is also negatived by the discovery announced by Mr. G. M. Dawson ("Science," April 20, 1888, p. 186) of small nephrite boulders on the upper part of the Lewes River, in British Columbia, not far from the eastern boundary of Alaska. But these nephrites are also strikingly like those from many other localities, and two of the latter have been included in my comparison. First, a dark green water-worn boulder from New Zealand, sent to the Museum by Sir Julius Haast; and, second, a small implement from Robenhause, Lake Pfäffikon, Switzerland, out of the collection of Mr. Thomas Wilson. The latter specimen, also green, had a specific gravity of 3.015, as determined by Dr. Hallock. The analyses are as follows:

	New Zealand.	Switzer- land.
Ignition	.83	.63
SiO ₂	56.73	56.87
Al ₂ O ₃	3.22	1.50
FeO	5.96	6.33
CaO	13.24	13.45
MgO	19.42	21.06
	99.40	99.84

All the iron is here represented as ferrous. Traces of manganese were present, but alkalies were not sought for.

Of jade objects from Mexico the Museum has a large and fine series; but nearly all of the specimens are from the one State of Oaxaca. The greater number of them are true jadeite; but as jadeite from the same region has been described by Damour,¹ a very exhaustive review of the material did not seem to be necessary. No nephrite was found in the Mexican series. Two specimens were analyzed, which may be described as follows. The specific gravity determinations are by Dr. Hallock.

A. Light-colored bead, mottled with emerald green. Specific gravity, 3.007.

B. Carved head, light green, from Zaachita. Specific gravity, 3.190.

¹ Bulletin de la Société Mineralogique, vol. 4, p. 157.

	A.	B.
Ignition	1.81	.53
SiO ₂	58.88	58.18
Al ₂ O ₃	25.93	23.53
Cr ₂ O ₃	.12	.....
FeO	.24	1.67
CaO	.40	2.35
MgO	.36	1.72
Na ₂ O	11.64	11.81
K ₂ O	.63	.77
	100.01	100.56

If the water (ignition) in A. be regarded as replacing alkalis, the mineral approximates closely to normal jadeite, $\text{AlNaSi}_2\text{O}_6$. Both analyses fit in well with Damour's work.

With Central American jade objects the Museum is well supplied. A few only are from Nicaragua and Guatemala. The finest are all Costa Rican. Here too jadeite is the dominant mineral species, although with the true jades are many articles of softer green stones, and occasionally an object of quartz or chalcedony. For analysis, four specimens were chosen, viz: two jadeites, one quartz-like mineral, and one of the softer minerals, as follows:

- A. Polished fragment, green. Rio de Buena Vista, Costa Rica. Specific gravity, 2.71, Clarke.
- B. Jadeite fragment. Sardinal, Costa Rica. Pale green, translucent. Specific gravity, 3.32, Clarke.
- C. Jadeite fragment. Culebra, Costa Rica. Light green, very granular, opaque. Specific gravity, 3.27, Clarke.
- D. Small ornament. Las Huacas, Costa Rica. Dark green, very soft. Specific gravity, 2.282, Hallock.

	A.	B.	C.	D.
Ignition		.90	.93	10.39
SiO ₂	97.10	59.18	58.33	70.49
Al ₂ O ₃	1.85	22.96	21.63	11.39
Fe ₂ O ₃	}	}	1.71	}
FeO			.73	
		1.87		2.39
MnO				trace.
CaO	none.	1.52	4.92	3.83
MgO	none.	.67	3.09	.57
Na ₂ O		12.71	8.13	undet.
K ₂ O		trace.	.22	undet.
	98.95	99.81	99.69	99.06

Of these analyses, A speaks for itself. In B and C we observe a difference in composition, which is in the line indicated by the appearance of the specimens; that from Sardinal being translucent and nearly

homogeneous; that from Culebra being coarser, distinctly mottled, and evidently impure. Specimen C is plainly not jade in any sense. It was examined microscopically by Mr. Merrill, who pronounced it to be a highly altered volcanic tuff, containing a considerable amount of bright green chlorite.

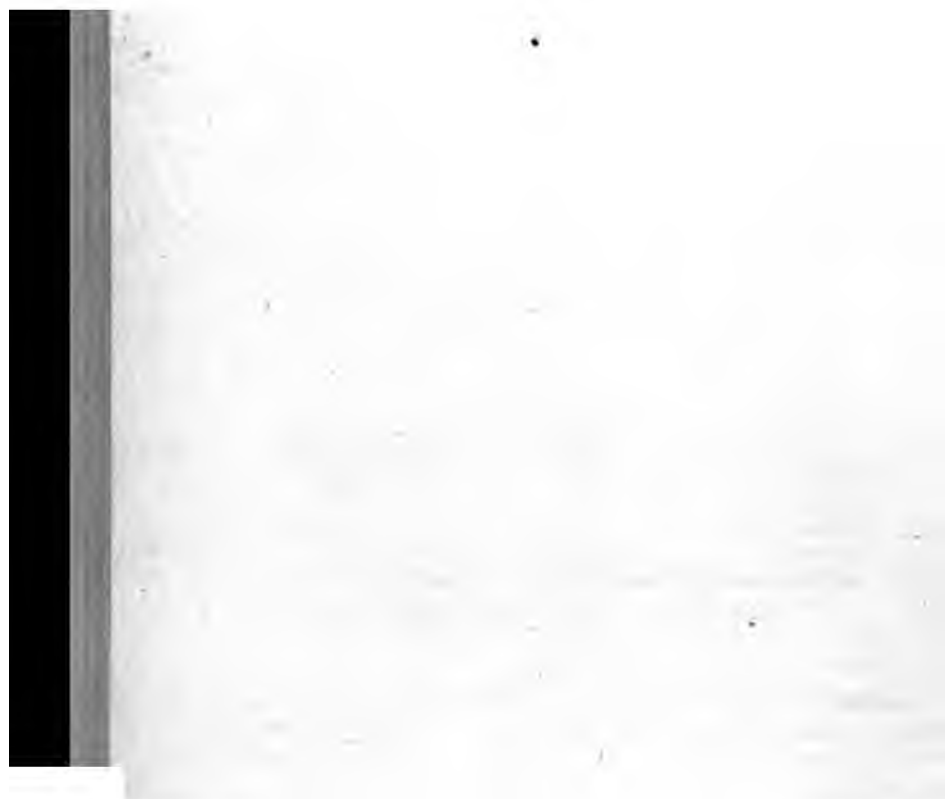
Through the kindness of Mr. Thomas Wilson, whose collection furnished the Robenhausen nephrite already described, I have been enabled to examine several other worked specimens of minerals which are sometimes classed, though loosely, with jade. A massive "saussurite" from the Saas Valley in Switzerland, out of the Museum collection, may be conveniently included in this series.

- A. Fibrolite implement from Brittany. Specific gravity, 3.147.
- B. Black stone implement from Estavayer, Lake Neuchatel. Specific gravity, 3.132.
- C. Dark green "saussurite" implement from Robenhausen. Specific gravity, 3.403.
- D. Massive "saussurite," Saas Valley.

The specific gravity determinations are due to Dr. Hallock.

	A.	B.	C.	D.
Ignition	1.31	.65	.30	.54
SiO ₂	34.66	45.13	46.90	48.29
Al ₂ O ₃	63.24	16.55	29.76	27.65
Fe ₂ O ₃	trace.	13.59	} 2.52	} 1.45
FeO		4.20		
MnO		trace.		
CaO	none.	11.02	11.77	12.95
MgO	.37	5.48	5.80	5.36
Na ₂ O		3.80	3.21	3.57
K ₂ O		trace.	trace.	trace.
	99.58	100.51	100.26	99.81

Microscopically studied the second of the specimens was found by Mr. Merrill to be a mixture of various minerals. It is evidently a highly altered "basic rock," possibly a diorite. The saussurites need no special discussion.



MINERALOGICAL NOTES.

1. PETALITE FROM PERU, MAINE. BY F. W. CLARKE.

In the well-known spodumene locality at Peru, Maine, petalite has been found in abundance. The discoverer, Mr. N. H. Perry, of South Paris, Maine, kindly furnished me with a fine suite of specimens, upon which the following examination was made. The petalite is intimately and irregularly intergrown with the spodumene, and occurs in white, pearly, cleavable masses much resembling some varieties of albite. To some extent it is stained by dendritic manganese; but in general the mineral is exceedingly pure. An analysis gave the following results, the lithia being determined by Gooch's process:

Ignition	1.03
SiO ₂	77.29
Al ₂ O ₃	16.95
Fe ₂ O ₃	trace.
MnO	trace.
Li ₂ O	2.62
Na ₂ O	2.39
K ₂ O	trace.
	100.28

2. SPESSARTITE FROM AMELIA COUNTY, VA. BY F. W. CLARKE.

This garnet, which is remarkable for its very high percentage of manganese, was analyzed at the request of Mr. G. F. Kunz. It occurs in the mica mines of Amelia county, in brilliant, brownish-red masses of considerable size. The specimen analyzed was very light in color, although some of the material was quite dark. The analysis was as follows:

Ignition	.27
SiO ₂	35.35
Al ₂ O ₃	20.41
Fe ₂ O ₃	2.75
FeO	1.75
MnO	38.70
MgO	none.
CaO	.94
	100.17

3. OLIGOCLASE FROM BAKERSVILLE, N. C. BY F. W. CLARKE.

This mineral, which was also received from Mr. Kunz, has been described by him¹ and also by Penfield and Sperry.² It occurs in color-

¹ Amer. Journ. Sci. (3), vol. 36, p. 222.

² Amer. Journ. Sci. (3), vol. 36, p. 324.

less or nearly colorless fragments of extraordinary transparency. Indeed, it resembles glass so nearly that at first sight one can hardly realize that it is a feldspar. The composition of the sample analyzed was as follows:

Ignition	.25
SiO ₂	62.92
Al ₂ O ₃	25.32
Fe ₂ O ₃	trace.
MnO	trace.
CaO	4.03
K ₂ O	.96
Na ₂ O	6.18
	99.66

4. WILLEMITE FROM THE TROTTER MINE, FRANKLIN, N. J. BY
F. W. CLARKE.

Collected by Mr. W. S. Yeates, and at first thought to be a new mineral. The specimens obtained were nearly pure white, granular, and quite unlike ordinary willemite in appearance. The following partial analysis, however, served to determine the species:

Ignition	.25
SiO ₂	27.41
ZnO	68.86
	96.52

A little manganese and iron are present, but were not determined.

5. DESCLOIZITE (?) FROM BEAVERHEAD COUNTY, MONT. W. F.
HILLEBRAND.

Through Messrs. W. H. Beck and George E. Lemon, of Washington, D. C., was received for examination a large lump of friable, uncrytallized material, having a dull yellow to pale orange color, and made up mainly of a vanadate, but carrying a large percentage of gangue. Two samples as pure as could be selected from different parts of the lump were analyzed with the following results:

	I.	II.	Mean.
PbO	56.02	55.84	55.93
CuO	1.16	1.13	1.15
FeO	0.70	0.70	0.70
ZnO	15.96	15.91	15.94
V ₂ O ₅		20.80	20.80
As ₂ O ₅	0.32		0.32
P ₂ O ₅	0.27		0.27
H ₂ O	4.37	4.36	4.37
SiO ₂	0.20	0.16	0.18
CaO	0.10		0.10
MgO	0.06		0.06
			99.62

From I 27.62 per cent. of gangue insoluble in cold dilute nitric has been deducted, and from II 22.20 per cent. Manganese was present in the gangue in small quantity, apparently as pyrolusite, but it was not dissolved by the acid. The insoluble portion was found also to retain very small quantities of lead and zinc, which were estimated and included in the analysis as probably belonging to the vanadate. The water had to be estimated indirectly by deducting from the total amount of water afforded by the dried mixture of vanadate and gangue that belonging to the latter alone, which was found as follows: The mixture dried at 100° C., was dissolved in cold dilute nitric acid, and the insoluble matter, collected in a Gooch crucible, was dried at the same temperature, and then ignited. The loss on ignition gave the water in the gangue, there being no ferrous iron in the latter to influence the result.

Neglecting the traces of SiO_2 , CaO , and MgO , as probably derived from the gangue, the following molecular ratio is obtained:

PbO	.2508	} .4718 or 4.02
CuO	.0145	
FeO	.0097	
ZnO	.1968	
V_2O_5	.1140	} .1173 or 1.00
As_2O_5	.0014	
P_2O_5	.0019	
H_2O	.2428	
		or 2.07

The water it will be noticed is double that required by descloizite, $\text{R}^+(\text{OH})^2(\text{VO}^4)^2$, but in view of the liability to error inherent in the method of water estimation employed, this is not deemed sufficient cause to separate the mineral from descloizite, although the close agreement of the two water determinations, made as they were on samples containing different proportions of gangue, would indicate the correctness of the formula $\text{R}^+(\text{OH})^2(\text{VO}^4)^2 + \text{H}_2\text{O}$, which is that of descloizite with a molecule of water of crystallization added.

This, so far as known, is the first observed occurrence of a lead vanadate in Montana. The precise locality of the mineral is the Mayflower Mine, in the Bald Mountain mining district.

6. PRELIMINARY REMARKS ON NORTH AMERICAN URANINITES BY W. F. HILLEBRAND.

A large crystal nearly an inch in diameter from Andrews's formerly Hales's quarry, in South Glastonbury, a few miles northeast of Middletown, Conn., showing octahedral, cubical, and dedecahedral faces, having been identified as uraninite with about 10 per cent. of thoria, the question arose: Was this thoria an essential constituent of the mineral or was its presence due to admixture of some thorium mineral, as thorite or orangite? With a view to settling this point a careful analysis was made accompanied by a microscopical examination of a thin section of the crystal. The results were not conclusive, therefore

other material from the same locality was sought for and obtained from Prof. W. N. Rice and Mr. E. F. Sheldon of Middletown, Conn. Analysis showed its chemical identity with the first specimen, and established beyond question that the thoria could not be derived from any thorium silicate. The observation was made that unless certain precautions were taken the estimation of UO_2 in the mineral was very unsatisfactory, and might be many per cent. too low. If a rather concentrated sulphuric acid is used for decomposing the mineral in sealed tubes, an insoluble uranous sulphate is formed which often crystallizes out in beautiful green crystals of considerable size, which dissolve very slowly when the contents of the tubes are emptied into cold water preliminary to titration with potassium permanganate. This defect was remedied by using a very dilute acid—1 vol. H_2SO_4 to 6 vols. H_2O —and the final reaction was then as sharp as could be desired. A more important precaution to be observed is the manner of filling the tubes with carbonic acid gas. This must invariably be done by introducing the gas from a generator and sealing during its introduction, and never by using sodium carbonate in the tubes themselves. In the latter case, before the seal can be made, outside air in greater or less amount is certain to enter and its oxygen is sufficient to lower the percentage of UO_2 found by several per cent., as repeatedly ascertained by actual experience.

The results thus obtained after employing every possible precaution to guard against oxidation of UO_2 or reduction of UO_3 during the process of decomposing the mineral and subsequent titration were perplexing to the last degree in view of the results arrived at by Comstock¹ and Blomstrand² independently of each other, which appeared to prove definitely that all varieties of uraninite could be considered as orthouranates of uranium and lead, in which thorium and other metals of the earths might replace basic uranium. The Glastonbury uraninite could by no possibility be referred to an orthouranate, but was a decidedly basic salt.

In extension of the investigation uraninite from Black Hawk, Colo., from North Carolina and from Branchville, Conn., was analyzed. The North Carolina material was so evidently in process of alteration, being seamed in every direction by very minute cracks filled with yellow decomposition products, that its analysis could give no clue to the relative proportions of the two oxides of uranium in the original fresh substance, but the presence of nearly 4 per cent. of rare earths—mainly thoria—was ascertained. The Branchville material was kindly given by Professors Brush and Dana, of New Haven, being the remainder of the stock from which the material for Comstock's analysis was taken. Its re-examination was undertaken with the view of ascertaining whether thoria had not been overlooked, as would almost certainly be the case had ammonium oxalate instead of oxalic acid been employed as a test

¹ *Am. Journ. Sci.* (3), vol. 19, 1880, p. 220.

² *Geol. Für. Förh.*, VII, 59, 1884, and *Journ. prak. Chem.*, XXIX, 191, 1884.

for the rare earths. This proved to be the fact, there being nearly 7 per cent. of thorium present in the mineral, which had undoubtedly been included in the UO_3 of Comstock's analysis. This alone would utterly invalidate the formula assigned by him, but in addition the UO_2 was found uniformly higher by many per cent. than his analysis showed. In different samples selected from the material at my disposal, however, the percentage was not the same, but differed by several units, and the density rose always with the percentage of UO_2 . The Colorado mineral, which unlike that from Connecticut and North Carolina does not occur crystallized, is likewise not referable to an orthouranate, being as basic as that from Glastonbury, Conn. It is remarkable for the low percentage of lead—less than 1 per cent. of oxide—and for the absence of any other qualitatively similar element, as well as for the presence of about 7 per cent. of zirconia; thorium being entirely wanting.

The question of the composition of this interesting mineral, which seemed so satisfactorily settled by the researches of Comstock and Blomstrand above referred to, must hence be considered as again opened for discussion. My own analyses and experiments are as yet too indecisive to admit of forming any conclusions entitled to weight as to the probable constitution of the mineral, but as opportunity offers they will be prosecuted, and extended to material from any other localities in this country or abroad that may become available, and will be published in detail at some future time.

Trifling amounts of rare earths other than thorium were found in the Glastonbury and Colorado specimens as well as in those from North Carolina.

7. DUMORTIERITE FROM NEW YORK AND ARIZONA. BY J. EDWARD WHITFIELD.

In the November (1887) number of the American Journal of Science Dr. R. B. Riggs published some observations, including a chemical analysis, on a mineral found at Harlem, N. Y., and generally supposed to be indicolite. The notice led to correspondence between Mr. J. S. Diller and Prof. E. S. Dana, the latter identifying it as dumortierite.

The composition, as determined by Dr. Riggs, conformed to no known mineral, and he was justified in provisionally calling it a new boro-silicate, but on further examination by Mr. Diller of a somewhat larger amount of material it was found that the mineral was associated with tourmaline, which no doubt accounts for the results of the analysis.

It was decided to analyze another portion which was known to be purer than that examined by Dr. Riggs. This was done, and the following figures are the results obtained: SiO_2 31.44 per cent.; Al_2O_3 68.91 per cent., with the smallest trace of boric acid. Their quantities compare fairly well with the theoretical amounts necessary to satisfy M. Damour's formula $\text{Al}_6\text{Si}_3\text{O}_{18}$ for dumortierite.

At about the time this work was being done on the New York

mineral, a small piece of rock from Clip, Arizona, was sent to the National Museum for identification. Prof. F. W. Clarke recognized it as a specimen of dumortierite accompanying quartz, and it was subjected to analysis to confirm his opinion. Following are the results of the examination :

	Per cent.
SiO ₂	31.52
Al ₂ O ₃	63.66
CaO.....	none.
MgO.....	.52
Na ₂ O.....	.37
K ₂ O.....	.11
B ₂ O ₃	2.62
Ignition.....	1.34
	100.14

These figures show that the mineral was rather impure, and it was thought advisable to obtain, if possible, more of the mineral, and endeavor to separate it as far as possible from the accompanying rock. Mrs. C. A. Bidwell, the sender of the first specimen, kindly furnished quite an amount of much better material, in which the only mineral associated with the dumortierite was quartz.

As dumortierite is not acted upon by hydrofluoric acid, the rock was crushed to small particles and digested in this acid for a length of time sufficient to remove most of the quartz. The mass was then washed with water, dried, and any quartz that might remain was separated by Thoulet's solution. After thorough washing, the material was examined with the aid of the microscope and found to be free from gangue.

After being ground exceedingly fine and dried at 104° C. for about three hours, the material was analyzed with the following results :

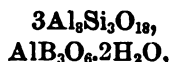
	Per cent.
SiO ₂	27.99
Al ₂ O ₃	64.49
P ₂ O ₅	.20
CaO.....	none.
MgO.....	trace.
B ₂ O ₃	4.95
H ₂ O.....	1.72
	99.35

These figures show less impurity than the first specimen analyzed; but if dumortierite is a simple silicate of alumina as stated, by M. Damour¹ these results either do not uphold his conclusions or they show the material to be a mixture of dumortierite and some other compound.

If we assume the formula of M. Damour to be correct and estimate all the SiO₂ in the analysis as belonging to the formula Al₆Si₃O₁₈, then there will be left unaccounted for a small amount of Al₂O₃, H₂O and

¹ Bull. de la Soc. Min. de France, vol. 4, p. 6.

B_2O_3 , and these are present in the proportions represented by the formula $AlB_3O_6 \cdot 2H_2O$. If this mode of interpretation be correct, then the mineral from Arizona corresponds approximately to the formula,



which requires Al_2O_3 65.2 per cent., SiO_2 27.6 per cent.; B_2O_3 5.4 per cent.; H_2O 1.8 per cent.; agreeing quite closely with the actual analysis. A berate of alumina corresponding to the above formula is, we believe, not actually known, and concerning its properties nothing can be predicated. If it exists, it is certainly remarkable that it should withstand the treatment with hydrofluoric acid which the Dumortierite received during the process of purification.

We are deeply indebted to Mrs. O. A. Bidwell for the supply of material for investigation, which at the cost of much personal labor she so liberally furnished.

8. XANTHITANE FROM NORTH CAROLINA. BY L. G. EAKINS.

Through the kindness of Mr. William Earl Hidden some fine specimens of xanthitane were obtained, the material coming from Green River, Henderson county, N. C. It was first described by C. U. Shepard in the American Journal of Science, 1856, vol. 22, p. 96.

The material I examined is evidently an alteration product of sphene, following the form very closely. It is light yellow, friable, and mixed with impurities which can not be removed, preventing the determination of whether or not it is a definite mineral; but it is interesting from the fact that it apparently represents a clay with the silica replaced by titanic oxide.

Specific gravity 2.941 at 24°. The air-dried material loses 6.02 per cent. of water at 100°. The following analysis is on material dried at 100°:

-	SiO_2	1.76
	TiO_2	61.54
	Al_2O_3	17.59
	Fe_2O_3	4.46
	CaO	0.90
	MgO	trace.
	P_2O_5	4.17
	H_2O	9.92
		100.34

9. TRIPLITE FROM THE BLACK HILLS, DAKOTA. BY L. G. EAKINS.

The material for this analysis was taken from a large specimen of several pounds weight, in the collection of the National Museum. It comes from a tin mine near Rapid City, S. Dak. In reality it probably

represents a mixture, but in general appearance it seems to be fairly homogeneous, and in composition it approaches closely to triplite.

It is brown in color, varying from light to dark, and translucent in thin pieces. In getting material for analysis any visible impurity was carefully picked out.

The composition is as follows:

SiO ₂	.43
Al ₂ O ₃	8.74
Fe ₂ O ₃	2.36
FeO	1.97
MnO	29.13
CaO	6.72
MgO	trace.
K ₂ O	trace.
Na ₂ O	5.25
Li ₂ O	.13
P ₂ O ₅	30.68
H ₂ O	3.67
F	2.35
Cl	.25
CO ₂	.26
	100.94
Less O	1.05
	99.89

10. KAOLIN FROM THE WATERFALL MINE, GUNNISON COUNTY, COLO.
BY L. G. EAKINS.

This mineral occurs in a large mass, filling a cavern which has been opened for mining purposes in Redwell Basin, Gunnison county, Colo. It is especially interesting on account of being the containing mass of aggregates of galena and pyrite crystals which are scattered irregularly through it.

It is very fine and white, and on slightly rubbing up with water the material as it comes from the mine it can easily be floated off in a pure condition.

The analysis is as follows:

SiO ₂	47.28
Al ₂ O ₃	36.19
Fe ₂ O ₃	trace.
CaO	.42
MgO	trace.
K ₂ O	5.74
Na ₂ O	.51
H ₂ O	8.72
P ₂ O ₅	.57
	99.43

11. NATIVE GOLD FROM PERSIA. BY CHARLES CATLETT.

The sample of gold, inclosing quartz, was submitted for assay through State Department by the American minister to Persia, and was property of the Persian Government. The specimen was of unusual interest as coming from a region so little known mineralogically. The native gold, which was of very light color, was analyzed with the following results:

Au.....	93.24
Ag.....	6.65
Fe.....	.11
Cu.....	none.
	100.00

PYROXENE AND SERPENTINE FROM MONTVILLE, N. J. BY CHARLES CATLETT.

The series in question was collected by Mr. G. P. Merrill, of the National Museum, and submitted to this laboratory for analysis. It consisted of a dark gray, and a white pyroxene (A and B), and a dark and a light serpentine (C and D), resulting from their respective alteration. An alteration product (E) closely related to the others was analyzed at the same time.

	A.	B.	C.	D.	E.
SiO ₂	51.45	48.17	40.23	42.38	4.32
Ignition	1.08	*.12	14.24	14.12	*1.26
CaO	24.02	21.96	trace.		
CaCO ₃		10.44			87.75
MgO	18.43	17.61	39.46	42.14	4.07
MgCO ₃		.71			1.67
Al ₂ O ₃	2.94	.52	2.18	.07	} .10
Fe ₂ O ₃	1.06	.18	4.02	.97	
FeO	.96	.24	trace.	.17	
MnO	trace.				
SO ₂	trace.	trace.			.13
K ₂ O	undet.	undet.	undet.	undet.	.12
Na ₂ O	undet.	undet.	undet.	undet.	.28
	99.94	99.95	100.13	99.85	99.70

* H₂O.



THE SUBSIDENCE OF FINE SOLID PARTICLES IN LIQUIDS.

[Second Paper.]

By CARL BARUS.

(1) In my earlier work I endeavored to analyze the phenomenon of sedimentation into parts such that the conditions under which subsidence is to be explained from a chemical, or from a physical point of view, may be better discernible.¹ To do this I first considered the question in its purely mechanical aspects.² If P is the resistance encountered by a solid spherule of radius r , moving through a viscous liquid at a rate x , and if k be the frictional coefficient, then $P=6\pi krx$. Again, the effective part of the weight of the particle is $P'=\frac{4}{3}\pi r^3(\rho-\rho')g$, where g is the acceleration of gravity and ρ and ρ' the density of the solid particle and the liquid, respectively. In case of steady motion $P=P'$. Hence

$$x=\frac{2}{9k}r^2(\rho-\rho')g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In any given case of thoroughly triturated material, the particles vary in size from a very small to a relatively large value; but by far the greater number approach a certain mean figure and dimension. An example of this condition of things may be formulated. To avoid mathematical entanglement I will select

$$y= ax^3e^{-x^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where y is the probable occurrence of the rate of subsidence x . If now the turbidity of the liquid (avoiding optical considerations) be

¹ The present article, being a continuation of Bull. U. S. G. S., No. 36, 1886, is largely based on the experimental evidence there tabulated. Mr. William Durham (Chem. News, vol. 30, 1874, p. 57; *id.*, vol. 37, 1878, p. 47) was the first to give an incentive to this class of experiments. Much of our knowledge of the effect of precipitants is due to him. Moreover, the theoretical views at which he ultimately arrives may be regarded as a definite point of departure. In this country, Prof. T. S. Hunt (Proc. Boston Soc. Nat. Hist., Feb., 1874), Prof. W. H. Brewer (National Acad. Sc. 1883; American Journ. Sci., series 3, vol. 29, 1885, p. 1), and Prof. C. R. Stuntz (Cincinnati Soc. Nat. Hist., Feb., 1886), have occupied themselves with similar work. Professor Stuntz's paper contains further references among others to Waldie's results (Journal Asiatic Soc., Bengal, 1873; Chem. News, 1873). Meanwhile Mr. William Hallock has made experiments on the subsidence of lamp-black in connection with his work on the density of that substance. (Cf. Bull. U. S. G. S., No. 42, 1887, p. 132.) I may add that my own experiments were suggested by Professor Brewer's memoir.

² Cf. Kirchhoff: Mathematische Physik, lecture 26, § 4, 1876.

defined as the mass of solid material per unit of volume of liquid, then the degree of turbidity which the given ydx particles add to the liquid is, caet. par., proportional to r^3ydx , where r is the mean radius. Hence the turbidity T , at the outset of the experiment (immediately after shaking), is

$$T = T_0 \int_0^{\infty} r^3 y dx = T_0$$

where equations (1) and (2) have been incorporated.

If the plane at a depth, d , below the surface be regarded, then at a time, t , after shaking, the residual turbidity there is

$$T = T_0 \int_0^d r^3 y dx = T_0 \left(1 - e^{-\frac{d^2}{t^2}} \left(1 + \frac{d^2}{t^2} \right) \right) \dots \dots (3)$$

This equation describes the observed occurrences fairly well. In proportion as the time of subsidence is greater, the tube shows opacity at the bottom, shading off gradually upward, through translucency, into clearness at the top. If, instead of equation (2), there be introduced the condition of a more abrupt maximum; if, in other words, the particles be very nearly of the same size, then subsidence must take place in unbroken column, capped by a plane surface which at the time zero coincided with the free surface of the liquid. Again, suppose one-half of the particles of this column differ in some way uniformly from the other half. Then at the outset there are two continuous columns coinciding, or, as it were, interpenetrating throughout their extent. But the rate of subsidence of these two columns is necessarily different, since the particles, each for each, differ in density, radius, and frictional qualities by given fixed amounts. Hence the two surfaces of demarkation, which at the time zero coincided with the free surface. In general, if there be n groups of particles uniformly distributed, then at the time zero n continuous columns interpenetrate and coincide throughout their extent. At the time t , the free surface will be represented by n consecutive surfaces of demarkation, below it, each of which caps a column, the particles of which form a distinct group. This phenomenon is Professor Brewer's stratified subsidence. In the case of particles which have undergone an earlier fractionated sedimentation, either in nature or in the arts, the occurrence of groups possessing the distinctive characteristics here discussed is not improbable. On the other hand, when during subsidence the surfaces of demarkation follow each other in regular succession, one is tempted to look for something more than an adventitious cause for the phenomenon. An orderly arrangement of groups of particles, might for instance, indicate successive stages of hydration. (Cf. § 6.) In case of stratified subsidence it is convenient to speak of orders of surfaces, numbering them from the top downward. It is not uncommon to observe seven or even ten consecutive orders.

(2) With these deductions as a point of departure, I then attempted to find relations between rates of subsidence, the viscous and capillary properties of the liquid, and its electrical behavior under analogous conditions of concentration and of temperature. This general survey proved that the phenomenon of sedimentation is unique; that the frictional resistances encountered by the particles are apparently different from the viscosities of the liquids in which subsidence takes place; that many of the occurrences observed are closely allied to the electrolytic and the capillary properties of this liquid. Finally, utilizing Professor Brewer's stratified subsidence, which I obtained very clearly with certain kinds of tripoli, I commenced a series of more rigorously quantitative measurements, showing that, *caet. par.*, rate of subsidence is primarily dependent on the turbidity of the mixture.

In my experiments with tripoli, the observed rates of subsidence ($\frac{\text{cm}}{\text{sec} \times 10^6}$) in ether, alcohol, water, glycerine, were 7500, 1300, 3, 0.9, respectively; but, owing to the difference in character of the divers precipitates, these figures have no further signification than to emphasize the said difference in character. (Of. §§ 5, 6.) Let water and ether be mixed so that there shall be equal bulks of etherized water below and aqueous ether above, and then let the dust (bole) be added. If now the mixture is violently shaken and then allowed to subside, the ether is washed clean of particles in a few minutes, whereas the sediments remain suspended in the water for weeks and even months. Here, however, the separation and subsidence are promoted by the surface energy of water. On the other hand, if dry tripoli be added to ether dried over CaCl_2 , in a test tube, and if the tube be held obliquely after shaking, subsidence is so rapid that the upward current of ether along the upper line of the tube is almost tempestuous.

The close relation of the present phenomena to electrolytic phenomena appears at once by observing that so little as a single molecule of HCl (for instance) added to 10,000 or even to 50,000 molecules of H_2O , produces appreciable increase of the rate of subsidence. Remembering that the arrangement is in three dimensions, and supposing the molecule HCl as large as the molecule¹ H_2O , the effect of the molecule HCl must be appreciated at a distance of at least 30 times its own radius, and extend much beyond this asymptotically. Quincke's radius of capillary attraction, .000005 cm , being about 100 times the molecular radius H_2O , it appears that the striking effect of the molecule HCl in accelerating subsidence is not an abnormal occurrence, at least when considered physically. Other points of view are given in the Bulletin.

(3) To account for these phenomena as a whole, Mr. Durham in his second paper (*l. c.*) proposes a hypothesis in virtue of which the scope of the action of affinity is enlarged, and suspension regarded as the lower limit of solution. This view is fast gaining ground; nevertheless,

¹ The estimated diameter of H_2O , distance between centers of adjacent molecules = $40/10^9\text{cm}$. Kohlrausch. *Wied. Ann.*, vol. 6, 1819, p. 209.

without concise experimental reference to the density and size of the solid particles, and the viscosity of the liquid, Mr. Durham's explanation contains no sufficient reason for the observed suspension, nor for changes of rate of subsidence. Prof. Brewer's ingenious hypothesis of colloidal hydrates, so constituted that the particles may ultimately swell up and float, something like gelatinous silica, or even like starch grains, is more direct; and before further reasons of the cause of suspension are sought, the validity of this inference must be tested. This test is feasible, I think. If the phenomenal difference of rate with which the same particles subside in water and in ether is due to volume changes of the particles, then a marked difference in the density of the sediment (clay or tripoli) in water and in ether, respectively, must be experimentally demonstrable. Cf. Equation (1). I made these experiments with both solids, using two nearly identical density flasks, one for water and the other for ether, in the usual way. The powders were sampled and dried at 200° in an air bath, for half a day, transferred to the pycnometers, dried and weighed when cold. They were then left in a desiccator for 18 hours and again weighed; and finally dried in vacuo, and weighed. The results throughout were satisfactorily constant. By aid of an apparatus specially devised for the purpose, the two flasks were once more thoroughly exhausted (mercury air-pump), and then filled with water and with ether, respectively, in vacuo, over sulphuric acid. In both cases (experiments made consecutively) the vacuum ebullition was kept up for some time to give full assurance of the expulsion of air, etc. The density of the ether had been previously determined by the same flasks, once for each experiment.

I thus obtained for tripoli

In water, density = $\Delta_w = 2.672$,

In ether, density = $\Delta_e = 2.697$.

Again I obtained for white bole

In water, $\Delta_w = 2.639$,

In ether, $\Delta_e = 2.663$.

The manipulation being somewhat difficult, the observed differences of Δ_w and Δ_e are no larger than the many sources of error led me to anticipate, particularly in view of the fact that the two samples, for ether and for water, may not have been absolutely identical. The concentrated ether used was the same commercial reagent with which I obtained the subsidence phenomena. In consequence of the high but normal values of both Δ_w and Δ_e , I saw no need of specially purifying it. I add finally that after calcination the dry tripoli lost 1.2 per cent. in weight, and the dry bole about 11.4 per cent. In both cases this is probably water of constitution, the elimination of which was of course not permissible. It is well to note that in spite of differences of chemical composition, bole particles are about equally well suspended before and after calcination, and the phenomena with ether dried over CaCl_2 are identical with the above.

(4) These results show that the densities in the two cases (sediment in water and in ether respectively) are not essentially different. Moreover, the density of tripoli is so near that of quartz, and the density of bole so near that of kaolinite, as to leave the hydration hypothesis very seriously in the lurch, so far as favorable evidence is concerned. It is improbable that the addition of water to the dry powder is accompanied by sufficiently marked volume changes; it is certain that the enormous variation of rates of subsidence actually observed, when the particles descend in water, in solutions, and in ether, must be referred to some general cause apart from the density of the particles and the viscosity of the liquids.

(5) This premised, the explanation of sedimentation may, I think, be satisfactorily based on the following principle: If particles of a comminuted solid are shaken up in a liquid, the distribution of parts after shaking will take place in such a way that the potential energy of the system of solid particles and liquid, at every stage of subsidence, is the minimum compatible with the given conditions. In the case of solid particles and pure water the configuration answering these conditions is schematically

Particle, water . . . particle, water.

In the case of solid particles and ether, or of solid particles and solutions, this configuration is schematically

Particle, particle . . . ether, ether.

For the truth of this inference, my paper contains abundant experimental evidence. The principle asserts that in case of water the sediment is graded and the suspended material granular, whereas in ether the sediment is apparently homogeneous, as I found; that the bulk of sediment is necessarily less in water than in ether, being compact in the first instance and of a microscopically arched or castellated internal structure, in the second instance, as I found; that the effect of a precipitant is particularly marked when the mixture is densely turbid with relatively coarse particles, as I found; that, finally, the phenomenon of sedimentation must be of a distinct and special kind, and by no means the immediate converse of capillary viscous transpiration. The inferences are thus based on equation (1) above, and follow at once when k and ρ are constant. In the Bulletin I computed the relative size (radii) of the particles of tripoli subsiding in water, alcohol, ether, to be 1, 19, and 24, respectively.¹ It is exceedingly curious to note in case of water,

¹ This is the first hypothesis developed in detail in Bull. U. S. Geol. Survey, No. 36, pp. 34, 35, 37. In a recalculation since made with more accurate value of k (water 0° to 100°, Slotte's data, in Wied. Ann. vol. 20, 1883, p. 262; ethyl and methyl alcohol, Graham's data in Phil. Mag. (4), vol. 24, 1861, p. 238; ether datum from Landolt and Boernstein's tables, p. 153; glycerine $\eta=10.0$ g cm.⁻¹ sec.⁻¹, estimated roughly), the radii of the particles in water, ethyl alcohol, methyl alcohol, ether and glycerine are found to be $r=0.000009$ cm, 0.00019 cm, 0.00018 cm, 0.00020 cm and 0.00005 cm, respectively. In case of bole suspended in water at 15° and at 100°, the radii were approximately <0.000010 cm and >0.000020 cm, respectively. Section 9

despite the phenomenally large surface energy of the liquid, the subsidence takes place in such a way that for a given mass of suspended sediment the surfaces of separation are a maximum. On the other hand, in case of subsidence in ether, or in salt solutions, the solid particles behave much like the capillary spherules of a heavy liquid shaken up in a lighter liquid with which it does not mix. In other words, the tendency is to reduce surfaces of separation to the least possible value, large particles growing in mass and bulk mechanically, at the expense of the smaller particles. Finally it is clear that the condition of stratified sedimentation is very slow subsidence of a granular precipitate.

(6) The experimental evidence adduced bears directly on the size of the particles of any precipitate. A given mass of small solid particles presupposed, the observations of the foregoing paragraphs make it probable that the potential energy of the system of solid particles and liquid increases with the radius of the particle. These observations also show that the potential energy of the system of solid particles alone decreases as the size of the particles increases, a state of things due both to the immediate action between solid particles and probably also to the surface energy of the liquid in which suspension takes place. Under these conflicting conditions it is probable that there is a critical shell within which the energy solid-liquid decreases less rapidly than the energy solid-solid; and beyond which shell the energy solid-liquid increases more rapidly than the energy solid-solid. This critical shell being compatible with the conditions of minimum potential energy of the subsiding system, as a whole, is the size of the precipitated particles; for any change of the radius of a particle bounded by the critical shell, implies an expenditure of work, which under the usual conditions of subsidence is not available.

(7) I have finally to endeavor to assign some value to the radius of the critical shell for the case of the above water suspensions. In my experiments with tripoli, rates of subsidence, x in $\text{cm}/(\text{sec} \times 10^6)$, varied from $x=1$ to $x=20$, according as higher orders of surfaces or turbidities of lower degree were chosen. Taking the more usual value $x=3$, the radius of the particles subsiding was probably not less than 400 times the molecular radius of water. The bole particles under analogous conditions of suspension in H_2O , were smaller, probably only 100 water radii. In Professor Brewer's indefinitely suspended clays, the limit of comminution can not be estimated at all, except perhaps from purely optical consideration.¹ Whether in this extreme case colloidal hydra-

points out, that whereas these dimensions may be called in question when considered absolutely, the relative values of radius are probably true.

The fact that particles so extremely light descend at all is a most striking result, showing the extreme delicacy of these experiments. In case of tripoli-water, for instance, the estimated weight of particles is only $1/10^{11}$ milligram. Being invisible microscopically it must weigh less than $1/10^{10}$ milligram.

¹The optical properties of light reflected from particles small in comparison with the wave length of light are discussed by Stokes (Phil. Trans., 1852, p. 530). How large a particle may be without interfering with optical clearness, I can not say.

tion with concomitant volume changes is still demonstrably absent, remains to be seen. To test it, a sufficient quantity of the extremely fine material would have to be collected and dried by low temperature evaporation, an excessively tedious task.

Again, in Bulletin No. 35, p. 21, I point out at some length that "when the particles decrease (in size) from some estimable mean value indefinitely," liquid viscosity, being at least partially, if not largely kinetic in character, can no longer be considered constant; that therefore a particle may descend, or in other words the continuous and constant action of gravity produce an effect even when the weight of the particle is below the mean or physically measurable value of the friction encountered; that the limits of time-variation of viscosity will increase as the radius of the circumscribed space decreases. In such a case the particle to be stationary must weigh less than the lower limit of the variable viscosity—a quantity which may reasonably be conceived to approach zero very nearly. I carried these inferences one step further by supposing, rationally I think, that the limits within which this *elementary* viscosity (say) varies, will increase with the degree of molecular agitation of the liquid. On the basis of this postulate I then endeavored to explain sedimentation kinetically, both in its relation to temperature and the effect of precipitants.

One point which antagonizes this hypothesis in part must not be lost sight of. Two or more particles sufficiently near together tend to screen each other, and, receiving impact mainly on their outer surfaces, will be held in permanent coherence so long as the conditions of pronounced molecular agitation last. This is observed to some extent in solution suspensions, ether suspensions, and in water suspensions at high temperatures (100°). There is therefore some difficulty in preserving the granular state (Bull. 36, p. 38).

To pass judgment on the validity of such an explanation, it is necessary to have in hand better statistics of the size of the particles relatively to the water molecules than are now available. Indeed whether the liquid water molecule is simply H_2O and not some more complex form can not at the present state of science be decided. Inasmuch as the particles in pure water are individualized and granular, it is apparently at once permissible to infer the size of the particles from the observed rates of subsidence. But my observations show that the said rates decrease in marked degree with the turbidity of the mixture. Hence the known formulæ for a single particle are not rigorously applicable though it can not be asserted whether the cause of discrepancy is physical or mathematical in kind. It follows that special deductions must be made for stated groups of particles before an estimate of their mean size can be fairly obtained.



A NEW METHOD OF MAKING ALLOYS.¹

BY WILLIAM HALLOCK.

While occupied with a careful study of an article by W. Spring² on the production of Wood's alloy, and seeking the forces possibly brought to bear in his experiments, the following explanation occurred to me, and was subsequently verified by critical experiments. The method of production used by Mr. Spring was to mix filings of the four metals in the proper proportions, subject the mass to a pressure of 6,000 atmospheres, file up the block thus produced and compress it a second time, obtaining as an end result a block of Wood's alloy.

Now, if at any time during the various operations, be it the first compression, the subsequent filing, or the second compression, or if anywhere in the whole mass, the original metals came in contact all together, then at that point we should have a particle, a molecule as it were, of Wood's alloy. If thereafter the temperature ever rose to 70° C., that particle would melt and dissolve down its immediate neighbors until finally the whole mass was liquefied and converted into a homogeneous mass of alloy. Without waiting to consider how improbable it was that the three or four metals could be brought simultaneously into perfect enough contact to act as a real alloy, I tried the experiment and it proved an easy success.

The metals were filed to fine grains and mixed in the proper proportions; one part cadmium, one part tin, two parts lead, and four parts bismuth. A glass tube of 5^{mm} inner diameter and 70^{mm} length, sealed at one end, served as containing vessel. About 6 grams of the mixed filings were placed in this tube and packed down, an iron wire 3^{mm} diameter, held between the thumb and finger, being used as a packer; which certainly eliminated the possibility of any considerable pressure. The tube was thereupon so placed upon the water-bath that the sealed end containing the metals projected downward into the boiling water. In this way the filings remained dry and were kept at a temperature of 98° to 100° C. After remaining in this position for eighteen hours (over night) the filings showed signs of sinking together, which would

¹ Read before the Philosophical Society of Washington, D. C., at the meeting of February 18, 1888.

² W. Spring: *Ber. der Chem. Gesell.*, vol. 15, 1882, pp. 595-597.

indicate a beginning of the reaction. The tube was jarred upon the table to assist the condensation and again placed on the bath. Two hours later the tube contained a *homogeneous liquid globule of Wood's alloy*. The experiment was repeated, using two larger tubes, into which the metals were packed with a lead pencil, and producing some 30 grams of alloy. Of course when the operation is once started there is no limit to the quantity which can be produced. One tube remained on the water-bath over a week without signs of a solution and yet finally dissolved.

In further application of the same principle lead and tin were melted together at 190° to 200° C. by simply laying a piece of tin upon a carefully cleaned piece of lead and placing the whole in an air-bath at 190° C. A few hours suffice for this experiment. The melting points of the above metals are—cadmium 315° C., tin 230° C., bismuth 267° C., lead 325° C. Potassium and sodium were also used, melting at $62^{\circ} 5'$ C. and $95^{\circ} 6'$ C. respectively.

A very interesting and striking experiment is the production of the alloy of equal parts of potassium and sodium, which is liquid at temperatures above 6° C. Pieces of the two metals are simply placed with freshly cut surfaces in contact and slightly pressed together; in a few seconds the liquid alloy, which resembles mercury, is visible in drops around the contact surface, and an hour or two suffices to produce several cubic centimeters of the fluid.

It is my intention in the near future to follow up these observations by a series of experiments intended to establish and extend the principle here illustrated. The heat phenomena which doubtless accompany these reactions will also be investigated. Possibly also some electrical manifestations may be discovered, and perhaps some facts bearing upon the origin of contact electricity may be developed. In the mean time I would propose the following law: An alloy can be produced out of its original constituents without considerable pressure if the temperature be above the melting point of the alloy, even though it be far below the melting point of the most easily fusible constituent.

Probably this law will also be found applicable wherever under the existing circumstances the product is a liquid, even though the original substances be solids.

MISCELLANEOUS ANALYSES.

ROCKS COLLECTED BY R. D. IRVING.

A. Separations from the gabbro of Ashland County, Wis.: 1, 1 spar; 2, diallage; 3, magnetite, partial.

[Analyses by W. F. Hillebrand.]

	No. 1.	No. 2.	No. 3.
H ₂ O	.23	.33	.....
SiO ₂	53.30	49.80	.....
TiO ₂	trace.	1.29	8.47
P ₂ O ₅	trace.	trace.	.....
Al ₂ O ₃	20.03	2.86	.....
Fe ₂ O ₃	.55	2.48	50.29
FeO	.23	10.82	30.70
MnO	none.	.37	.....
SrO, BaO	traces.	none.	.....
CaO	11.40	16.50	.....
MgO	.13	15.33	.....
K ₂ O	.40	.12	.....
Na ₂ O	4.87	.51	.....
Li ₂ O	none	trace?	.....
	100.14	100.41	89.46

B. Garnet, separated from the garnetiferous actinolite schist Penokee Gap, Wis.:

[Incomplete analysis on only 0.54 gram, by T. M. Chatard.]

SiO ₂	39.31
Al ₂ O ₃	12.86
Fe ₂ O ₃ (total iron)	46.66
MnO	1.03
CaO	1.88
MgO	1.90

103.64

The excess, 3.64, is oxygen added to ferrous iron. Correcting, we approximately Fe₂O₃, 10.21; FeO, 32.81.

C. Limestones and iron carbonates: 1, Limestone, near S^W Lake, Gogebic district, Mich.; 2, Limestone, Penokee region, V

cherty iron carbonate, Gogebic district; 4, iron carbonate, outlet of Sunday Lake; 5, iron carbonate, Palms mine, Gogebic district.

[Analyses by W. F. Hillebrand.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
H ₂ O	.30	.27	.54	.68	.60
CO ₂	45.31	46.27	41.10	25.21	19.24
SiO ₂	3.07	.63	3.16	28.86	46.47
TiO ₂				.20	.10
P ₂ O ₅			.06	trace.	trace.
Cl	trace.	trace.	trace.		(?)
Al ₂ O ₃			.08	1.29	.70
Fe ₂ O ₃	.09	.03	.93	1.01	.86
FeO	.09	.75	15.18	37.37	28.57
MnO	.15	.08	1.15	.97	.40
CaO	29.72	30.94	26.65	.74	.49
MgO	19.95	20.68	11.01	3.64	2.30
FeS ₂			.34		
Organic matter				undet.	undet.
	99.45	99.65	100.20	99.97	99.73

(Same series continued): 6, Iron carbonate, Miner and Wells' option, Sec. 13, T. 47 N., R. 46 W., Michigan; 7, "iron carbonate," bed of Slate Creek, Huron Bay slate quarries, Michigan; 8, iron carbonate, north-west $\frac{1}{4}$ Sec. 18, T. 47, R. 45 W., Minnesota; 9, slaty rock, supposed iron carbonate, bed of Cross River, near Gunflint Lake, Michigan.

[Analyses by T. M. Chatard.]

	No. 6.	No. 7.	No. 8.	No. 9.
H ₂ O	1.71	.25	1.52	1.99
CO ₂	17.72	39.68	22.44	.41
SiO ₂	46.01	7.05	36.73	64.77
TiO ₂	.12	none?	.19	.60
P ₂ O ₅	.07	.27	.01	.20
SO ₃	.15	.21	.16	.60
Al ₂ O ₃	.83	.48	.38	14.45
Fe ₂ O ₃	1.35	1.33	.98	1.84
FeO	26.07	undet.	34.81	4.54
MnO	2.04	.19	.52	.11
CaO	.63	50.08	.48	2.33
MgO	2.86	.57	2.74	2.34
Alkalies	undet.	undet.	undet.	K ₂ O 5.03 Na ₂ O 1.37
	99.61	100.11	100.96	100.58

(Same series continued): 10, Iron carbonate, west end of Gunflint Lake, Minnesota; 11, iron carbonate, north side of lake; 12, limestone, east end of Ogiskemannissi Lake, Minnesota; 13, limestone, north side of Gunflint Lake, Canada.

[Analyses by T. M. Chatard.]

	No. 10.	No. 11.	No. 12.	No. 13.
H ₂ O	2.08	1.22	1.07	.99
CO ₂	5.22	19.96	24.70	32.42
SiO ₂	58.23	46.46	41.99	23.90
TiO ₂	trace?	trace?	trace?	none.
P ₂ O ₅	.03	.13	.06	trace?
SO ₃	.19	.14	.32	.17
Al ₂ O ₃	.06	.24	1.24	.07
Fe ₂ O ₃	5.01	.64	.42	.44
FeO	18.48	26.34	4.77	10.72
MnO	.25	.21	.26	.28
CaO	.38	1.87	16.85	22.25
MgO	9.59	3.10	8.41	8.52
Alkalies	undet.	undet.	undet.	undet.
	99.52	100.31	100.08	99.76

NOVACULITE FORM MARQUETTE, MICH.

[Collected by G. H. Williams; analyzed by W. F. Hillebrand.]

H ₂ O	2.35
SiO ₂	76.99
P ₂ O ₅	trace.
Al ₂ O ₃	13.92
Fe ₂ O ₃	.45
FeO	.77
MnO	trace.
CaO	.32
MgO	1.12
K ₂ O	3.65
Na ₂ O	.56
Li ₂ O	trace.

100.13

BRICK-CLAY FROM NEW ULM, MINN.

Color greenish-gray. Brick made from it is reddish-brown, strongly sintered, somewhat fractured. Received from Hon. John Lind.

[Analyzed by T. M. Chatard.]

Ignition	10.73
SiO ₂	61.32
TiO ₂	.66
P ₂ O ₅	.27
SO ₃	.19
Al ₂ O ₃	12.27
Fe ₂ O ₃	3.62
FeO	4.18
MnO	.27
BaO	.05
CaO	.99
MgO	1.76
K ₂ O	3.59
Na ₂ O	.42

100.32

ROCKS FROM MONTANA.

[Collected by A. C. Peale and G. P. Merrill.]

A. From hills east of Fort Ellis: 1, Rock, analysis by T. M. Chatard; 2, ground mass; and 3, portion soluble in hydrochloric acid, analyzed by L. G. Eakins.

	A. 1.	A. 2.	A. 3.
H ₂ O	5.42	1.90	.....
SiO ₂	46.90	65.23	26.88
TiO ₂	.41	.....	.....
P ₂ O ₅	.44	.....	.....
Al ₂ O ₃	10.17	17.48	3.89
Cr ₂ O ₃	.33	.....	.....
Fe ₂ O ₃	1.22	.98	2.21
FeO	5.17	.....	4.28
MnO	.10	.....	trace.
CaO	6.20	3.08	1.61
MgO	20.98	2.02	16.44
K ₂ O	2.04	4.63	trace.
Na ₂ O	1.16	3.79	trace.
Insoluble .....	.....	.....	51.29
	100.54	99.11	100.00

B. From hills north of Camp 6 (Peale), East Gallatin River.

C. Partial analysis of vein from rock north of East Gallatin River.

[Analyses by L. G. Eakins.]

	B.	C.
H ₂ O	4.14	.....
SiO ₂	49.47	65.19
TiO ₂	.21	.....
P ₂ O ₅	.37	.....
CO ₂	3.31	.....
Al ₂ O ₃	12.15	16.38
Cr ₂ O ₃	trace	.....
Fe ₂ O ₃	1.93	2.31
FeO	4.07	.....
MnO	.10	.....
BaO	.03	.....
CaO	9.30	.56
MgO	10.86	.....
K ₂ O	2.42	8.09
Na ₂ O	2.08	1.71
	100.44	94.24

D. From Cottonwood Creek: 1, Rock, analysis by T. M. Chata
 portion soluble in dilute hydrochloric acid, analysis by L. G. Eaki

	D. 1.	D. 2.
H ₂ O	3.19	.....
SiO ₂	51.65	12.94
TiO ₂	.55	.....
P ₂ O ₅	.21	.....
SO ₂	.19	.....
Al ₂ O ₃	13.89	2.93
Cr ₂ O ₃	.08	.....
Fe ₂ O ₃	2.70	} 5.07
FeO	4.80	
MnO	.15	trace.
BaO	.19	.....
CaO	4.07	.90
MgO	11.56	8.28
K ₂ O	4.15	.33
Na ₂ O	2.99	.39
	100.37	30.90

E. Porphyrite, Cottonwood Creek: 1, Complete; 2, portion solu
 dilute hydrochloric acid.

[Analyses by L. G. Eakins.]

	E. 1.	E. 2.
H ₂ O	2.68	.....
SiO ₂	52.33	13.62
TiO ₂	.14	.....
P ₂ O ₅	1.02	.....
Al ₂ O ₃	15.09	5.93
Fe ₂ O ₃	4.31	.....
FeO	4.03	.....
MnO	.09	.....
BaO	.07	.....
CaO	7.06	.....
MgO	6.73	.....
K ₂ O	3.76	.08
Na ₂ O	3.14	.78
	100.45	20.41

F. and G. Two rocks from northwest of Cottonwood Creek.

[Partial analyses, as requested, by L. G. Eakins.]

	F.	G.
SiO ₂	62.98	54.29
Al ₂ O ₃	18.44	18.47
Fe ₂ O ₃	2.49	5.67
CaO	1.79	3.69
MgO		3.98
K ₂ O	4.35	5.92
Na ₂ O	5.58	4.13
	95.63	96.15

H. Eight carboniferous limestones. Analyses by C. Catlett: 1, north of East Gallatin River; 2, west of North Bowlder River; 3, 4, north of East Gallatin River; 5, west side of Bridger Range, base of carboniferous; 6, north of Gallatin River, middle formation; 7, 8, north of Gallatin River, upper formation.

	H. 1.	H. 2.	H. 3.	H. 4.	H. 5.	H. 6.	H. 7.	H. 8.
CaCO ₃	54.54	54.54	67.85	59.11	88.50	91.96	32.28	40.21
MgCO ₃	43.63	42.62	6.18	1.96	.95	1.35	13.91	25.25
Fe ₂ O ₃	} .22	.40	2.50	1.92	.38	.58	.30	5.30
Al ₂ O ₃								
Insoluble ..	.34	1.78	23.50	35.26	9.98	5.99	50.74	25.24
Water, etc..	undet.	undet.	undet.	undet.	undet.	undet.	undet.	undet.
	98.73	99.34	100.03	98.25	99.81	99.83	97.23	96.00

ERUPTIVE ROCK FROM THE HENRY MOUNTAINS, UTAH.

[Received from J. S. Diller; analyzed by R. B. Riggs.]

H ₂ O	.69
SiO ₂	63.16
TiO ₂	.21
P ₂ O ₅	.12
SO ₃	trace.
Al ₂ O ₃	17.21
Fe ₂ O ₃	2.43
FeO	2.30
MnO	trace.
CaO	6.27
MgO	1.27
SrO	trace †
BaO	.09
Li ₂ O	trace
Na ₂ O	4.70
K ₂ O	1.84

100.29

ROCKS FROM NEW MEXICO.

[Collected by J. W. Powell; analyzed by L. G. Eakins.]

A. Obsidian from Obsidian Hill Camp.

H ₂ O	.33
SiO ₂	76.20
TiO ₂	trace.
Al ₂ O ₃	13.17
Fe ₂ O ₃	.34
FeO	.73
MnO	.10
CaO	.42
MgO	.19
K ₂ O	4.46
Na ₂ O	4.31
	100.25
Specific gravity.....	2.352, 23° 5'

B, C, D, and E. Four basalts, Rio Grande Cañon.

	B.	C.	D.	E.
H ₂ O	.82	.64	1.29	.53
CO ₂	trace.	.58	.37	.....
SiO ₂	52.27	51.57	52.37	52.38
TiO ₂	1.49	1.43	1.60	1.22
P ₂ O ₅ .....	.....	.....	.....	.56
Cl	trace.	.....	trace.	.....
Al ₂ O ₃	17.68	17.72	17.01	18.79
Fe ₂ O ₃	2.51	6.24	1.44	2.88
FeO	5.00	1.78	5.89	4.90
MnO	.23	.45	.32	.18
BaO	.06	.16	.06	.11
CaO	8.39	8.82	7.59	7.70
MgO	6.05	4.91	6.86	4.91
K ₂ O	1.58	1.99	1.59	1.76
Na ₂ O	4.19	3.59	3.51	3.99
	100.27	99.88	99.90	99.91

LAVAS FROM NEAR LASSEN PEAK, CALIFORNIA.

[Series collected by J. S. Diller.]

1. West end of Lake Bidwell.
2. Silver Lake.
3. Volcanic sand, half-mile northeast of Cinder Cone, 10 miles north-east of Lassen Peak.
4. Inclusion in lava of Cinder Cone.
5. Lava of volcanic bomb, from Cinder Cone.
6. One-third of a mile south of Cinder Cone, on border of lava field.
7. Lapilli from Cinder Cone.

8. Timber line, west base of Lassen Peak.
9. Lava enveloping No. 8.
10. East end of Chaos, northwest base of Lassen Peak.
11. East end of Chaos, northwest base of Lassen Peak.
12. Two miles south of Luffan's Mountain, Llana County.
13. Two miles south of Luffan's Mountain, Llana County.
14. Northwest base of Luffan's Mountain, at base of high cliffs near Lassen Peak.
15. West side of old crater near Thumb, head of Mill Creek.
16. One mile southwest of Thumb, at head of Bailey Creek.
17. Lava resting on dacite, near west base of Lassen Peak.
18. One and one-half miles northeast of Clipper Mills, on tramway to Rock Creek, Shasta County.
19. West summit of Crater Mountain.
20. North slope of Crater Mountain.
21. Nodule from No. 20.
22. Near eastern end of rim, Crater Mountain.
23. South base of Burney Butte.
24. Cone at south base of Burney Butte.
25. Northwest summit in rim about the head of Burney Creek.

[Analysis 1 to 21 by W. F. Hillebrand; 22 to 25 by R. B. Riggs.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
H ₂ O	.42	.86	.26	.68	.30	.28	.27	.91
SiO ₂	56.18	57.59	55.93	79.49	56.70	54.56	56.53	55.14
TiO ₂	16.59	16.49	17.34	11.60	.65	.53	.54	.52
P ₂ O ₅					.20	.18	.15	.18
Al ₂ O ₃					15.75	16.04	17.50	19.10
Cr ₂ O ₃					trace.	trace.	trace.	none.
Fe ₂ O ₃	1.51	1.22	1.50	.33	1.29	.95	1.35	6.16
FeO	5.51	4.80	5.20	.49	5.32	6.07	5.03	.54
MnO	undet.	undet.	undet.	none.	.19	.17	.12	.11
BaO	(?)	(?)	(?)	(?)	.03	.03	trace.	trace.
SrO	(?)	(?)	(?)	(?)	trace.	trace.	(?)	.07
CaO	7.64	7.40	8.04	1.64	7.67	8.89	8.07	8.36
MgO	7.26	7.72	7.29	.09	7.16	8.71	5.94	4.23
K ₂ O	1.47	.99	1.35	1.52	1.56	1.18	1.55	1.04
Na ₂ O	3.58	3.62	3.32	4.04	3.36	3.05	3.51	3.71
Li ₂ O	(?)	(?)	(?)	(?)	trace.	trace.	trace.	trace.
	100.16	100.78	100.23	99.88	100.18	100.64	100.56	100.07

MISCELLANEOUS ANALYSES.

	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.	No. 16.
H ₂ O	1.37	.74	.77	.55	1.00	1.09	1.03	1.04
SiO ₂	68.32	68.72	63.35	63.47	57.04	58.08	63.81	59.84
TiO ₂	.31	.31	.56	.37	.47	.44	.38	.57
P ₂ O ₅	.12	.09	.10	.13	.08	.16	.10	.19
Al ₂ O ₃	15.26	15.15	19.22	16.75	19.11	18.37	17.07	16.81
Cr ₂ O ₃	none.	none.	none.	trace?	none.	none.	none.	trace?
Fe ₂ O ₃	1.66	1.16	3.28	2.15	4.37	2.92	2.11	1.88
FeO	1.26	1.76	4.48	2.75	2.48	3.38	2.15	3.60
MnO	.04	.11	.15	.09	.12	.13	.09	.14
BaO	.07	.07	(1)	.04	trace?	.03	.04	.07
SrO	trace.	.03	.03	.04	.02	.02	.03	.02
CaO	3.26	3.30	9.76	5.72	7.34	7.05	4.97	6.30
MgO	1.32	1.28	4.86	3.04	3.94	3.35	2.28	3.86
K ₂ O	2.81	2.78	.99	1.62	1.16	1.33	1.96	2.13
Na ₂ O	4.27	4.26	2.89	3.94	3.48	3.66	4.08	3.63
Li ₂ O	trace.	trace.	trace.	trace.	trace.	trace.	trace.	trace.
	100.07	99.76	100.44	100.66	100.70	100.01	100.10	100.07

	No. 17.	No. 18.	No. 19.	No. 20.	No. 21.	No. 22.	No. 23.	No. 24.	No. 25.
H ₂ O	.60	.85	.40	.83	.45	1.47	1.02	.79	.9
SiO ₂	56.51	74.60	68.12	61.17	53.85	52.95	62.44	52.63	60.0
TiO ₂	.48	.16	.25	.45	.50	.66	.31	.07	.4
P ₂ O ₅	.14	.03	.14	.14	.06	trace.	.05	.47	.0
SO ₂						trace.	trace.	trace.	trace
Al ₂ O ₃	18.10	13.41	16.24	17.74	18.53	18.25	16.39	17.62	17.4
Cr ₂ O ₃	trace.	none.	none.	none.	trace.				
Fe ₂ O ₃	4.26	1.28	1.26	1.78	1.96	4.36	4.66	6.49	5.3
FeO	2.68	.30	2.08	3.51	5.30	4.19	1.00	3.10	.5
MnO	.11	.06	.10	.12	.12	.12	Trace.	Trace.	.0
BaO	.04	.11	.09	.06	.03	.01	.63	.04	.0
SrO	.04	none.	.02	.04	.04	trace.	trace.	trace.	(?)
CaO	8.15	1.08	3.80	5.90	9.06	8.73	6.22	8.62	6.6
MgO	4.52	.26	1.35	2.76	5.88	4.93	2.65	5.64	3.5
K ₂ O	1.15	4.50	2.54	1.71	.74	.77	2.25	1.73	1.2
Na ₂ O	3.23	3.38	3.89	3.79	2.08	3.57	3.16	3.38	4.1
Li ₂ O	trace.	trace.	trace.	trace.	trace.	(?)	trace.	trace.	trace
	100.10	100.02	100.28	100.00	100.09	100.01	100.18	100.58	100.4

BASALT, ISLAND OF MYTILENE, ASIA MINOR.

[Collected by J. S. Diller; analyzed by T. M. Chataud.]

H ₂ O	2.12
CO ₂	2.32
SiO ₂	56.58
TiO ₂	.77
P ₂ O ₅	.15
Al ₂ O ₃	14.88
Cr ₂ O ₃	trace?
Fe ₂ O ₃	2.31
FeO	3.04
MnO	.16
CaO	8.69
BaO	.07
MgO	3.76
K ₂ O	2.18
Na ₂ O	3.36
	100.39

INCLUSION IN DIORITE FROM CRUGER'S STATION, NEAR PEEKSKILL,
NEW YORK.

[Collected by G. H. Williams; analyzed by T. M. Chataud.]

H ₂ O	4.61
SiO ₂	32.73
Al ₂ O ₃	46.58
FeO	5.12
CaO	11.04
MgO	1.00
	101.08

Analysis made on only 0.4212 gramme. The mineral is margarite.

WHITE EARTH FROM TALLADEGA, ALA.

[Received from R. A. Moseley, jr.; analyzed by C. Catlett.]

Ignition	1.94
SiO ₂	88.92
Al ₂ O ₃	7.47
Fe ₂ O ₃	trace.
CaO	.18
MgO	trace.
Alkalies	undet.
	98.51

SANDSTONE, BEREA, OHIO.

[Extensively quarried; analyzed by L. G. Eakins.]

H ₂ O	1.19
SiO ₂	92.91
Al ₂ O ₃	3.78
Fe ₂ O ₃	trace.
FeO	.91
CaO	.31
MgO	trace.
K ₂ O	.61
Na ₂ O	.34
	100.95

KNOX DOLOMITE AND RESIDUAL CLAY.

[From Morrisville, Ala.; collected by I. C. Russell; analyzed by W. F. Hillebrand.]

	Dolomite.	Clay.
SiO ₂	3.24	55.42
Al ₂ O ₃	.17	22.17
Fe ₂ O ₃	.17	8.30
FeO	.06	trace.
CaO	29.58	.15
MgO	20.84	1.45
K ₂ O		2.32
Na ₂ O		.17
H ₂ O	.30	9.86
CO ₂	45.54	
	99.90	99.84

Of the water in the clay 2.10 per cent. was expelled at 100°.

DOLOMITE FROM TUCKAHOE, WESTCHESTER COUNTY, N. Y.

The so-called "Tuckahoe marble." Extensively used as a building one. White, highly crystalline.

[Analysis by W. F. Hillebrand.]

Insoluble	1.33
H ₂ O	.16
Fe ₂ O ₃	.21
CaO	30.68
MgO	20.71
CO ₂	46.66
	99.75

Of the insoluble portion, 0.71 is silica. The iron is probably in part FeO.

WHITE DOLOMITE MARBLE, COCKEYSVILLE, MD.

[Analysis by J. E. Whitfield.]

SiO ₂	.44
Al ₂ O ₃	1.22
FeO	trace.
CaO	30.73
MgO	20.87
CO ₂	45.85
Ignition	1.22
	100.33

MARBLE FROM LOUISIANA.

From sections 19 and 20, T. 11 N., R. 3 W., five miles west of Winnfield. White, abundantly streaked with black. Received from the Supervising Architect of the Treasury.

[Analyzed by W. F. Hillebrand.]

Insoluble	.65
H ₂ O	.13
CaO	55.01
MgO	.60
MnO	.10
CO ₂	43.43
SO ₃	.27
	100.19

Traces of Al₂O₃, FeO, BaO, SrO, Cl, and organic matter.

LIMESTONES FROM OHIO AND INDIANA.

Trenton limestones and Utica shales, collected by Professor Edward Orton in the course of an investigation of the oil and gas wells of the two States. Partial analyses, as called for.

A. From New Vienna, Ohio. Analyses by F. W. Clarke and R. B. Riggs, jointly. 1, 2, 3, Utica shales. 4, 5, 6, 7, Trenton limestones.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
CO ₂	15.24	27.16	27.40	36.20	37.64	42.04	30.82
CaO	17.11	33.43	35.27	46.16	49.01	51.18	23.00
MgO	1.25	2.16	1.32	1.52	.58	3.08	12.90
Insoluble ...	60.17	29.51	25.80	8.47	9.93	2.12	28.43
	93.77	92.26	89.79	92.35	97.10	98.42	95.15

Iron and alumina present in the soluble portions.

B. Trenton limestones from Ohio. Analyses by Clarke and Riggs. 8, Arcadia, Hancock County; 9, Air-line Junction, Toledo; 10, gas rock, St. Henry's well, Mercer County; 11, oil-rock, Lima.

	No. 8.	No. 9.	No. 10.	No. 11.
CO ₂	38.54	42.84	40.96	43.92
CaO	47.17	30.64	50.34	32.24
MgO	2.59	18.05	2.86	17.36
Insoluble ...	8.56	3.52	2.27	1.64
	96.86	95.03	96.43	95.16

Iron and alumina present in the soluble portions.

C. Seven Trenton limestones from Ohio. Analyzed by F. W. Clarke. 12, well No. 3, Bryan, gas rock; 13, McElree well, Kenton; 14, Huntsville; 15, Prospect; 16, Findlay street well, Dayton; 17, Xenia; 18, New Madison. Air-dried samples.

	No. 12.	No. 13.	No. 14.	No. 15.	No. 16.	No. 17.	No. 18.
Insoluble . . .	9.22	5.26	4.41	26.12	12.34	9.23	11.11
Fe ₂ O ₃ , Al ₂ O ₃ . . .	1.51	1.10	3.15	2.57	.58	.18	3.60
CaCO ₃	49.00	84.32	57.23	66.02	82.36	86.54	64.91
MgCO ₃	38.59	8.43	33.16	3.77	1.67	2.99	17.98
	98.32	99.11	97.95	98.48	96.95	98.94	97.60

In 14 and 18 ferrous carbonate was present.

D. Seventeen Trenton limestones from Ohio. Analyses by C. Catlett. 19, Air-line Junction, Toledo, depth 1,415 feet; 20, Upper Sandusky, city well No. 2; 21, Sandusky, depth 2,260 feet; 22, St. Mary's township, Auglaize County, gas-rock, Pauck well; 23, same locality, gas-rock, Bennett well; 24, Carey, first city well, depth about 1,350 feet; 25, Fort Recovery well No. 2, depth 1,065 feet; 26, Loomis and Nyman well, Tiffin, depth 1,470 to 1,481 feet; 27, Loomis and Nyman well, Tiffin, 1,488 to 1,494 feet; 28, gas-rock, Waggoner well, 6 miles west of Fremont; 29, London, depth 1,594 feet; 30, Celina, depth 1,112 feet; 31, Port Clinton, 1,660 to 1,700 feet; 32, Wauseon, 2,135 feet; 33, Napoleon, 1,830 feet; 34, oil rock, Kossuth, Allen County; 35, Franklin Township, Mercer County; Doenze's well, 1,107 feet.

	No. 19.	No. 20.	No. 21.	No. 22.	No. 23.	No. 24.	No. 25.	No. 26.
Insoluble	2.88	8.18	3.65	3.18	1.66	5.72	1.89	5.66
Fe ₂ O ₃ , Al ₂ O ₃	8.68	4.31	4.58	3.12	2.48	3.08	1.57	4.86
CaCO ₃	54.68	64.25	54.62	52.18	56.94	80.11	87.88	53.89
MgCO ₃	25.73	15.93	33.67	38.42	35.55	8.09	7.43	33.46
	91.97	92.67	96.52	96.90	96.63	97.00	98.77	96.87

	No. 27.	No. 28.	No. 29.	No. 30.	No. 31.	No. 32.	No. 33.	No. 34.	No. 35.
Insoluble	9.88	5.22	15.90	2.95	7.46	18.24	2.66	1.08	3.68
Fe ₂ O ₃ , Al ₂ O ₃	1.46	0.32	1.84	2.95	4.16	7.28	2.14	.66	8.38
CaCO ₃	79.39	52.93	77.69	68.41	71.96	42.82	53.85	90.72	69.53
MgCO ₃	6.20	32.75	1.80	24.18	14.34	28.11	37.33	6.69	10.68
	96.93	97.22	97.32	98.49	97.92	96.45	95.98	99.15	92.27

WASHINGTON LABORATORY.

[BULL. 60.]

A. Six Trenton limestones from Indiana. 1, Union City, 1,160 feet; Bluffton, 1,062 to 1,067 feet; 3, Muncie, 920 feet; 4, Greensburg, feet; 5, Vernon, 905 feet; 6, Wabash, about 900 feet.

[Analyses, 1, by F. W. Clarke; 2, 3, 4, 5, 6, by C. Catlett.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Insoluble . . .	2.14	2.37	3.30	.87	8.00	3.52
Fe ₂ O ₃ , Al ₂ O ₃ . . .	1.23	4.48	3.72	.55	.60	7.58
CaCO ₃	83.21	53.43	51.96	94.60	85.56	53.18
MgCO ₃	12.48	37.47	38.11	.36	trace.	30.53
	99.06	97.75	97.09	96.38	94.16	94.81

COQUINA, CORAL, CORAL ROCKS, ETC.

Collected by Professor N. S. Shaler in an investigation of coral reefs. Partial analyses, as called for.

A. Five coquina gravels from Florida; 1, 2, 3, 4, Tortugas; 5, Key West; samples air-dried.

[Analyses by F. W. Clarke.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Moisture	3.27	3.57	5.12	3.07	3.19
CO ₂	41.46	41.07	40.39	41.53	41.58
SiO ₂	.19	.22	.32	.21	.25
Al ₂ O ₃ , Fe ₂ O ₃	.19	.47	.56	.76	.56
CaO	52.24	51.24	49.38	51.95	51.52
MgO	1.53	2.09	1.93	1.44	2.08
	98.88	98.66	97.70	98.96	99.18

Chlorides and sulphates present; phosphates not looked for.

B. Five coral and shell rocks from Florida; 6, near Fort Worth; 7, east side of St. John's River, near Seville; 8, corroded surface, Miami Reef; 9, near Oak Hill; 10, near Melbourne.

[Analyses by F. W. Clarke.]

	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
Moisture	2.64	3.37	2.33	3.21	2.53
CO ₂	41.59	39.00	41.22	39.62	34.31
SiO ₂	2.94	8.50	2.99	5.87	17.83
Al ₂ O ₃ , Fe ₂ O ₃	.23	.73	.65	.95	1.18
CaO	51.51	47.29	51.22	50.34	43.85
MgO	.71	1.51	.06	.37	.26
	99.62	100.40	98.37	100.36	99.96

C. Three coquinas from Florida; 11, coarse shell mass, Senote; 12, Salt Key Bank, coral rock; 13, Loggerhead Key.

[Analyses by L. G. Eakins.]

	No. 11.	No. 12.	No. 13.
H ₂ O	.11	1.13	.81
CO ₂	43.89	43.87	43.71
SiO ₂	.22	.11	.20
Al ₂ O ₃ , Fe ₂ O ₃	.18	.04	.22
CaO	54.87	53.54	53.54
MgO	.64	.71	.78
	99.91	99.40	99.26

D. Hammock clay, Melborne Creek, Florida.

E. Incrustation formed by evaporating waters, Everglades, Florida.

F. Ochreous deposit, Paint Rock, Dade County, Fla.

[Analyses by L. G. Eakins.]

	D.	E.	F.
H ₂ O	} 23.61	19.56	.31
CO ₂		25.38	} 41.30
Organic matter		19.68	
SiO ₂	38.04	1.59	1.32
Al ₂ O ₃	} 27.19	} 1.11	.30
Fe ₂ O ₃			7.26
FeO			.68
MnO			trace.
CaO	10.73	31.32	48.96
MgO	.46	.30	.41
Alkalies	undet.	undet.	
	100.03	98.94	100.64

G. Phosphatic deposit, Island of Sombbrero, West Indies.

H. Coralline bottom, Barbados.

I. Recent coral (*Siderostria*), Bermuda.

[Analyses by L. G. Eakins.]

	G.	H.	I.
H ₂ O	3.05	2.73	.54
CO ₂	3.47	43.40	43.74
Cl	.66		
P ₂ O ₅	39.12		
SiO ₂	.14	1.17	.23
Al ₂ O ₃	.29	.31	trace.
CaO	51.15	46.45	55.16
MgO	trace.	5.15	.20
	97.88	99.21	99.87

Alkalies not looked for,

J. Fourteen coral rocks and one soil from the Hawaiian Islands. Analyzed by L. G. Eakins. 1, Laie; 2, 3, Kohuku Bluff; 4, Kohuku coral flat; 5, point near coral flat; 6, modern chalk, Oahu; 7, Diamond Head; 8, under lava, Honolulu; 9, near Pearl River lagoon; 10, old reef, Waialua; 11, Campbell's Ranch quarry, Waianea, Oahu; 12, Wailuku Bay; 13, Reef Three, Honolulu; 14, Prison Knoll, Honolulu; 15, Lava soil, Diamond Head.

[Analyses by L. G. Eakins.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
H ₂ O.....	4.74	.40	.79	.93	.70	2.84	1.86
CO ₂	41.89	44.33	43.64	43.89	43.95	11.09	40.81
SiO ₂	.35	.19	.67	.25	.26	33.25	2.97
Al ₂ O ₃	.19	.52	.73	.49	.21	19.53	2.68
Fe ₂ O ₃						10.71	
CaO.....	49.38	49.34	51.09	53.34	52.17	11.37	44.82
MgO.....	1.74	4.60	2.50	.67	1.51	3.06	5.32
	98.29	99.38	99.42	99.57	98.80	98.85	98.66

	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
H ₂ O.....	1.61	16.84	1.33	.46	1.93	2.75	1.24	5.30
CO ₂	38.71	none.	42.68	43.96	42.80	40.59	42.81	11.41
P ₂ O ₅								.24
Cl.....								.91
SiO ₂	5.34	46.22	1.05	.53	.45	3.53	.81	32.88
Al ₂ O ₃	5.11	19.16	1.26	.62	1.82	2.26	1.19	12.02
Fe ₂ O ₃		12.94						11.52
MnO.....								trace.
CaO.....	42.24	1.72	51.07	50.69	50.54	46.52	52.67	12.20
MgO.....	5.95	2.24	.11	2.98	1.83	2.45	.42	11.70
Alkalies.....								undet.
	98.96	99.12	97.50	99.24	99.37	98.10	59.14	98.18

IRON AND MANGANESE ORES.

Two iron ores and two ochres from the Lucas farm, Jefferson County W. Va. Received from D. B. Lucas.

[Analyzed by C. Catlett.]

	Ore.		Ochre.	
	A.	B.	C.	D.
SiO ₂	1.18	4.03	92.07	93.57
Fe.....	58.72	59.31	2.72	2.24
Mn.....	none.	none.	undet.	undet.
P.....	.075	trace.	undet.	undet.
S.....	.293	trace.	undet.	undet.

ore, Little's ore bank, Jefferson County, W. Va., and Hostler's ore bank, same county. From D. B. Lucas.

[Examined by C. Catlett.]

	Little's.	Hostler's.
SiO ₂	55.67	67.34
Fe	23.21	22.73

ore from D. B. Lucas, iron ore from Cool Spring ore bank, Clarke County, Va., and from Bear Pond, top of Blue Ridge, Va.

[Analyses by C. Catlett.]

	Cool Spring.	Bear Pond.
SiO ₂	29.63	7.11
Fe	36.50	48.24
Mn	trace.	1.625
P	.175	.041
S	.232	.156

ore manganese ores, from Elkton, Rockingham County, Va. Referred to by C. E. Creecy.

[Analyzed by C. Catlett.]

	A.	B.	C.
Mn	43.94	49.66	48.75
SiO ₂	15.88	1.80	15.08
Fe	3.43	8.53	2.79
P	.166	.076	.085
S	.07	.089	trace.

ore iron and manganese ores, Stuart estate, Lick Mountain, near Lexington, Va. From J. W. Reardin.

[Analyses by J. E. Whitfield.]

	A.	B.	C.	D.
Fe	2.02	2.57	1.98	48.088
Mn	51.05	41.80	57.67	4.54
P	.161	.035	.000	.394
S	trace.	.00	.067	.056
Insoluble	4.32	4.05	1.85	10.34

Also three ores from the same estate, sent in by P. B. Thompson, jr. Same analyst.

	A.	B.	C.
Fe	34.05	38.01	3.96
Mn	4.93	15.23	44.60
P	.118	.05	9.45
S	.083	.088	trace.
Insoluble	34.59	9.31	15.81

Ores collected by Prof. J. R. Procter. Analyses partly by J. E. Whitfield, partly by C. Catlett.

A. From Scott County, Va.: 1, Anderson lands, near top of Clinch Mountain, southern slope, 1,150 feet above the railroad water-tank; 2, James Boatwright's land, east side of Stony Creek, Buffalo Ridge; 3, Clinch River Hills, land of J. C. Taylor's heirs, north side of the river, $3\frac{1}{2}$ miles above Stock Creek; 4, Slip Hill ore, where North Fork of Clinch River cuts through Purchase Ridge.

[Analyses 1, Catlett; 2, 3, 4, Whitfield.]

	No. 1.	No. 2.	No. 3.	No. 4.
Fe	51.98	47.22	49.79	11.543
Mn	4.60	trace.	trace.	none.
P	1.466	.093	.205	.275
S	.086	.119	.008	.08
Insoluble	2.07	25.56	17.332	59.366

B. From Wise County, Va.: 1, 2, 3, Big Stone Gap, top, middle, and bottom layers; 4, $1\frac{1}{4}$ miles from Big Stone Gap; 5, lands of Virginia Coal and Iron Company. All the deposits are on the south slope of Wallen's Ridge.

[Analyses by Whitfield.]

	1, top.	2, middle.	3, bottom.	4.	5.
Fe	6.65	49.44	49.44	39.76	52.00
Mn	.30	trace.	none.	.47	trace.
P	.096	.015	.122	.260	.165
S	.136	.132	.135	.085	.08
Insoluble	80.38	21.75	24.52	36.64	11.17

C. From Lee County, Va.: 1, A. J. Ely's land, north slope of Poor Valley Ridge, near Pennington Gap; 2, land of W. M. Pennington, near Pennington Gap.

[Whitfield, analyst.]

	No. 1.	No. 2.
Fe	52.82	20.76
Mn	trace.	trace.
P	.124	.33
S	.115	.079
Insoluble	17.92	64.43

D. Iron ore, three miles east of Pineville, on north slope of Pine Mountain, Bell county, Ky.

[Analysis by Catlett.]

Fe.....	43.32
Mn	1.27
P.....	.120
S	.342
SiO ₂	13.48

E. Supposed iron ore, one-half mile west of top of Flint Hill, two and one-half miles from North Carolina line, on the waters of Elk, Carter County, Tenn.

[Whitfield, analyst.]

Insoluble	88.48
Fe.....	5.83
Mn	1.35
P.....	.043
S	.039

F. Iron ores from Claiborne County, Tenn.: 1, outcrops 100 yards east of the Russell shaft, four miles southwest of Cumberland Gap; 2, Oty shaft, east end of Double Mountain, one and one half miles west of Cumberland Mountain; 3, Van shaft, southern slope of Double Mountain, one-half mile west of Gap Creek, two and one-half miles southwest of Cumberland Gap; 4, red fossil ore, three miles east of Big Creek Gap, southern slope of Cumberland Mountain; 5, red fossil ore, 200 yards east of Big Creek, 175 feet above creek, on southern slope of mountain, Big Creek Gap.

[Analyses by Catlett.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
SiO ₂	4.28	7.43	10.79	6.70	5.66
Fe.....	55.16	54.94	44.71	54.54	53.43
Mn	.09	.30	trace.	.43	.53
P.....	.010	.124	.108	.72	.243
S	.162	.087	.269	.214	.187

G. Ores from Unicoi County, Tenn.: 1, Garland land, on ridge between Rock and Martin's Creeks; 2, land of W. and M. Peebles, northern slope of Little Iron Mountain, near top of spur; 3, northwest spur of Unaka Mountains, one and one-half miles south of Irwin; 4, old mine on the Farnum land, at base of hill opposite mouth of Sciatha Creek; 5, divide between the waters of Rock and Dix Creeks, Hann tract; 6, Bell lands, on ridge west of Rock Creek, one and one-half miles east of Irwin, 700 feet above Irwin; 7, land of W. F. Norris, six miles from Johnson City, three-fourths of a mile southeast of Buffalo Creek; 8, west end of Little Iron Mountain, about one mile west of

mill, near top of hill; 9, one-fourth mile southeast from Blue Spring, on waters of Indian Creek.

[Analyses by Whitfield.]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Fe	46.41	54.69	2.70	23.55	41.63	56.32
Mn	3.47	trace.	44.94	32.98	12.13	trace.
P	.741	1.102	.282	.551	1.237	1.432
S	.077	none.	none.	none.	.057	.059
Insoluble ..	5.06	6.51	3.14	5.11	3.85	3.32

[Analyses by Catlett.]

	No. 7.	No. 8.	No. 9.
Fe	2.04	46.37	51.40
Mn	39.37	.38	3.01
P	.116	.509	.761
S	trace.	.106	.092
SO ₂	18.10	3.77	6.26

Iron ore, Cranberry Bed, Mitchell County, N. C.

[Analysis by Whitfield.]

Fe	51.65
Mn	.36
P	trace.
S	.081
Insoluble ..	19.95
TiO ₂ , Ni	traces.

Ores collected by L. C. Johnson in Louisiana: 1, Miller's Bluff, Bossier Parish; 2, Aubrey, Claiborne Parish; 3, Gilmer field, Phelps Lake, Bossier Parish.

[Analyses by Catlett.]

	No. 1.	No. 2.	No. 3.
Fe	38.35	43.17	49.97
P	.18	1.65	.62
S	.34	.056	.08
Insoluble ..	21.40	11.42	12.15

Ores from Arkansas, received from Hon. W. C. Whitthorne, from a mountain ridge crossing the line between Polk and Montgomery Counties, between the two Salinas Creeks: A, manganese; B, iron ore.

[Analyses by C. Catlett.]

	A.	B.
SiO ₂	4.64	.94
Mn	38.33	1.32
Fe	18.68	54.30
S	.170	.162
P	.56A	1.826

Iron ore from Wood County, Wisconsin. Section 32, T. 24, R. 4 E.
Received from T. E. Nash.

[Analyzed by J. E. Whitfield.]

Fe.....	22.15
Mn.....	trace.
S.....	.008
P.....	.030
Insoluble.....	57.70

Manganese ore (impure rhodochrosite), from Llanbedr, Harlech,
Merionethshire, Wales. Analyzed by T. M. Chatard, at request of Dr.
D. T. Day, for purposes of comparison with certain American material.

CO ₂	19.04
Mn.....	31.12
Al ₂ O ₃	7.63
Fe.....	4.02
SiO ₂	21.69

COAL AND COKE.

Two samples of coke from near Piedmont, W. Va. Received from
G. W. Harrison.

[Analyses by C. Catlett.]

	Thomas mine.	Davis mine.
Moisture.....	.47	.25
Volatile carbon.....	2.39	2.24
Fixed carbon.....	87.14	89.23
Ash.....	10.00	2.28
	100.00	100.00
S.....	.721	.645

Two samples of coal from near Piedmont, W. Va. Received from
Hon. H. G. Davis.

[Analyses by C. Catlett.]

	Elk Garden mine.	Davis mine.
Moisture.....	.76	.70
Volatile carbon.....	19.39	22.03
Fixed carbon.....	72.99	70.53
Ash.....	6.86	6.74
	100.00	100.00
S.....	.880	.924

Ash white, coke silver gray and porous.

Supposed anthracite from near Romney, W. Va. Received from A. W. Kercheval. A shale.

[Analyzed by C. Catlett.]

Moisture.....	.68
Volatile carbon.....	7.32
Fixed carbon.....	5.37
Ash.....	86.63

Three samples coal, Sharp bank, East Fork of Big Creek, Claiborne County, Tenn. Received from J. R. Procter.

[Analyzed by C. Catlett.]

	Top.	Middle.	Bottom.
Moisture	2.40	2.10	1.78
Volatile carbon	36.81	33.76	39.14
Fixed carbon	57.88	51.29	56.00
Ash	2.91	12.85	3.08
	100.00	100.00	100.00
S	1.087	1.15	2.30

Coke hard to burn; dark in color; ash brown.

Coal from Pend d'Oreille, Oregon. From Hon. J. K. Jones.

[Analysis by C. Catlett.]

Moisture	7.56
Volatile carbon.....	52.55
Fixed carbon	30.43
Ash.....	9.46
	100.00
S	.65

EFFLORESCENCE ON SANDSTONE, FROM CLIFF CREEK, GUNNISON COUNTY, COLO.

[Collected by Whitman Cross; analyzed by L. G. Eakins.]

	Soluble in water.		Insoluble.
Al ₂ O ₃	trace.	SiO ₂	55.09
CaO	trace.	Al ₂ O ₃	9.75
MgO	5.42	Fe ₂ O ₃	1.23
SO ₃	10.31	CaO	.30
		MgO.....	.39
		Alkalies.....	undet.
	15.73		66.76

Water.....	16.88
Soluble.....	15.73
Insoluble.....	66.76
	99.37

The soluble part is essentially MgSO₄, 7H₂O.

COMMON SALT, FROM HUTCHINSON, KANSAS.

[Received from Hon. P. B. Plumb, analyzed by T. M. Chatard.]

H ₂ O	.92
Insoluble	.09
CaSO ₄	1.47
MgCl ₂	.25
NaCl	97.27

100.00

WATER FROM LINCOLN COUNTY, N. C.

Spring on the farm of Willis E. Hall, 3 miles from Lowesville post office, and 20 miles from Charlotte.

[Analysis by F. W. Clarke. Stated in grammes per litre. Total solids, 0.642 gram.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0385	5.99	SiO ₂	.0385
Cl	.0029	.45	CaSO ₄	.4716
SO ₄	.3329	51.86	CaCO ₃	.0318
Ca	.1514	23.58	MgCO ₃	.0328
Mg	.0094	1.47	KCl	.0042
Na	.0267	4.16	NaCl	.0015
K	.0022	.34	Na ₂ CO ₃	.0601
CO ₂ difference	.0780	12.15		.6405
	.6420	100.00		99.77 per cent. of total.

SURFACE DRAINAGE WATER, ST. AUGUSTINE, FLA.

[Collected by William Kennish; analyzed by T. M. Chatard. Stated in grammes per liter.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0146	2.40	SiO ₂	.0146
Al ₂ O ₃ +Fe ₂ O ₃	.0015	.25	Fe ₂ O ₃	} .0015
Ca	.0796	13.12	Al ₂ O ₃	
Mg	.0166	2.74	NaCl	.1625
Na	.0639	10.53	KCl	.0188
K	.0098	1.61	CaSO ₄	.0742
SO ₄	.0524	8.64	CaH ₂ C ₂ O ₄	.2341
Cl	.1076	17.74	MgH ₂ C ₂ O ₄	.1099
CO ₂	.2450	40.40		
H in bicarbonates	.0042	.69		
	.5952			
Deficit of CO ₂	.0114	1.88		
	.6066	100.00		.6066

WATER FROM SPRING AT M'LEANSBOROUGH, ILL.

[Received from S. W. Heard; analyzed by R. B. Riggs. Stated in grammes per liter.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SO ₄	3.0040	59.59	KCl	.0220
CO ₃	.7903	13.90	NaCl	.0396
Cl	.0345	.68	Na ₂ SO ₄	.8433
SiO ₂	.0142	.28	MgSO ₄	2.2340
Al ₂ O ₃	trace.		CaSO ₄	.9166
Ca	.5420	10.75	CaCO ₃	.1924
Mg	.4468	8.86	CaH ₂ C ₂ O ₆	.7903
Na	.2888	5.73	SiO ₂	.0142
K	.0115	.21		
	5.0426	100.00		5.0524
H, bicarbonate	.0098			
	5.0524			

WATER FROM LEBANON, LACLEDE COUNTY, MO.

[From a well 1,000 feet deep. Received from Hon. R. P. Bland; analyzed by L. G. Eakins. Stated in grammes per liter.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0112	3.90	SiO ₂	.0112
Al ₂ O ₃	.0032	1.11	Al ₂ O ₃	.0032
Fe	trace.		NaCl	trace.
Ca	.0326	11.35	MgSO ₄	.0060
Mg	.0163	5.68	FeH ₂ C ₂ O ₆	trace.
Na	.0127	4.42	MgH ₂ C ₂ O ₆	.0917
SO ₄	.0048	1.67	CaH ₂ C ₂ O ₆	.1315
Cl	trace.		NaHCO ₃	.0370
CO ₃	.2030	70.69	Na ₂ CO ₃	.0066
H, bicarbonate	.0034	1.18		
	.2872	100.00		.2872

MISCELLANEOUS ANALYSES.

TWO SPRINGS AT HOMINY HILL, ARK.

[Received from Hon. A. H. Garland. Analyses by J. E. Whitfield. Stated in grammes per lit

A. OLD OR UPPER SPRING.

	Found.	Per cent. of total solids.		Hypo- tical combi- nation.
SiO ₂	.0122	7.21	SiO ₂	.0122
Fe, Al	traces.		CaSO ₄	.0058
Br, I	none.		CaH ₂ C ₂ O ₄	.0994
B ₂ O ₃	none.		MgH ₂ C ₂ O ₄	.0207
Cl	trace.		KHCO ₃	.0103
SO ₄	.0041	2.42	NaHCO ₃	.0219
CO ₂	.1117	65.98		
Ca	.0260	15.36		
Mg	.0034	2.01		
K	.0040	2.36		
Na	.0060	3.54		
Li	trace.			
NH ₄	none.			
H, bicarbonate	.0019	1.12		
	.1693	100.00		.1693
Free CO ₂	.0276		Free CO ₂	.0276

B. NEW OR LOWER SPRING.

SiO ₂	.0100	9.39	SiO ₂	.0100
Fe	trace.		CaSO ₄	.0121
Al	none.		CaH ₂ C ₂ O ₄	.0535
Br, I, B ₂ O ₃	none.		MgH ₂ C ₂ O ₄	.0146
Cl	trace.		KHCO ₃	.0031
SO ₄	.0085	7.98	NaHCO ₃	.0131
CO ₂	.0629	59.13		
Ca	.0168	15.79		
Mg	.0024	2.25		
K	.0012	1.13		
Na	.0036	3.39		
Li	trace.			
NH ₄	none.			
H, bicarbonate	.0010	.94		
	.1064	100.00		.1064
Free CO ₂	.0091		Free CO ₂	.0091

WATER FROM A SPRING NEAR DENVER, COLO.

Received from Sidney Williams; analyzed by L. G. Eakins. Stated in grammes per kilo. Specific gravity 1.063, at 20° C.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0290	.05	KCl	.2542
Cl	1.5862	2.62	NaCl	2.4143
SO ₄	43.9675	72.56	Na ₂ SO ₄	18.0629
AlFe	traces.		MgSO ₄	38.7306
Ca	.3214	.53	CaSO ₄	1.0029
Mg	7.7461	12.79	SiO ₂	.0290
K	.1331	.22		
Na	6.8006	11.23		
Li	trace.			
	60.5839	100.00		60.5839
CO ₂	.2101			
Album. NH ₃	.0050			
Free NH ₃	trace.			

MATILJA HOT SPRINGS, NEAR SAN BUENAVENTURA, CAL.

[Received from Dr. Stephen Bowers; analysis by R. B. Riggs. Stated in grammes per liter.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0088	.53	KCl	.0622
SiO ₂	.0412	2.51	NaCl	1.3876
Cl	.8768	53.20	MgCl ₂	.0068
SO ₄	.0169	1.02	MgSO ₄	.0073
CO ₃	.0579	3.51	CaSO ₄	.0160
Ca	.0650	3.94	CaCO ₃	.0965
Mg	.0034	.21	CaSiO ₃	.0629
Na	.5456	33.11	SiO ₂	.0088
K	.0325	1.97		
	1.6481	100.00		1.6481

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 61



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890

WATER FROM A SPRING NEAR DENVER, COLO.

Received from Sidney Williams; analyzed by L. G. Eakins. Stated in grammes per kilo. Specific gravity 1.063, at 20° C.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0290	.05	KCl	.2542
Cl	1.5862	2.62	NaCl	2.4143
SO ₄	43.9675	72.56	Na ₂ SO ₄	18.0629
Al, Fe	traces.		MgSO ₄	38.7306
Ca	.3214	.53	CaSO ₄	1.0929
Mg	7.7461	12.79	SiO ₂	.0290
K	.1331	.22		
Na	6.8006	11.23		
Li	trace.			
	60.5839	100.00		60.5839
CO ₂	.2101			
Album. NH ₃	.0050			
Free NH ₃	trace.			

MATILJA HOT SPRINGS, NEAR SAN BUENAVENTURA, CAL.

[Received from Dr. Stephen Bowers; analysis by R. B. Riggs. Stated in grammes per liter.]

	Found.	Per cent. of total solids.		Hypothetical combination.
SiO ₂	.0088	.53	KCl	.0622
SiO ₂	.0412	2.51	NaCl	1.3876
Cl	.8768	53.20	MgCl ₂	.0068
SO ₄	.0169	1.02	MgSO ₄	.0073
CO ₂	.0579	3.51	CaSO ₄	.0160
Ca	.0650	3.94	CaCO ₃	.0965
Mg	.0034	.21	CaSiO ₃	.0629
Na	.5456	33.11	SiO ₂	.0088
K	.0325	1.97		
	1.6481	100.00		1.6481

DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

N o . 61



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

CONTRIBUTIONS

TO THE

MINERALOGY OF THE PACIFIC COAST

BY

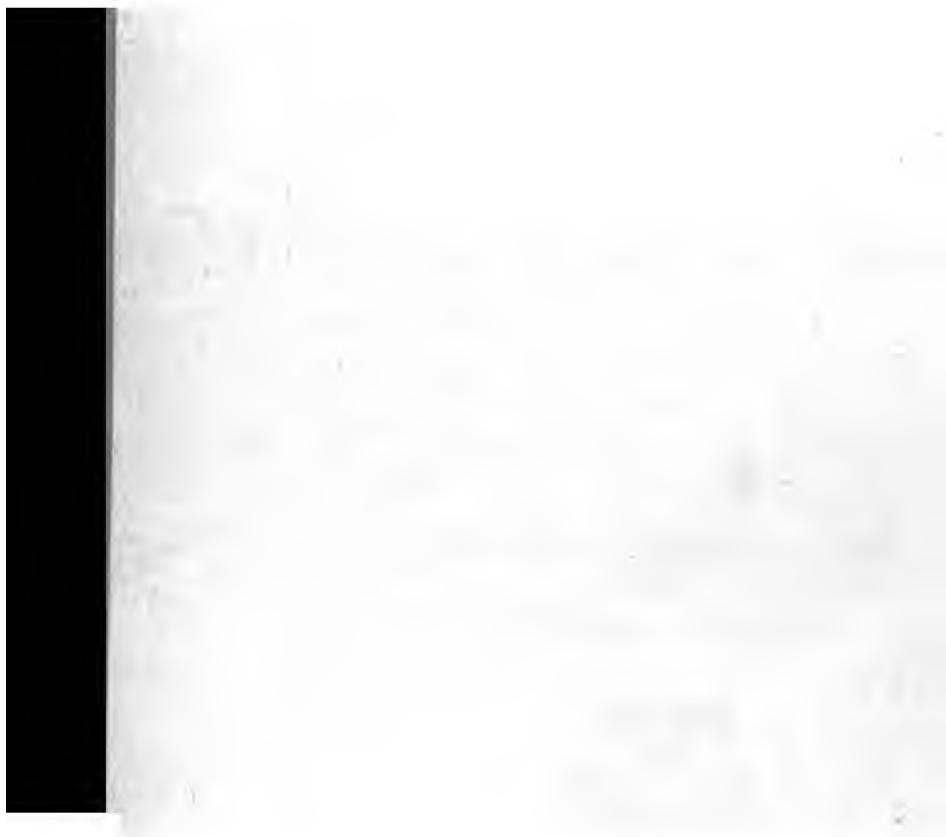
WILLIAM HARLOW MELVILLE

AND

WALDEMAR LINDGREN



WASHINGTON
GOVERNMENT PRINTING OFFICE
1890



CONTENTS.

	Page.
Letter of transmittal	9
Cinnabar crystals from New Idria, Fresno County, California.....	11
Cinnabar crystals from Sulphur Bank, Lake County, California	21
Cinnabar crystals from Knoxville, Napa County, California.....	22
Cinnabar crystals from New Almaden, Santa Clara County, California.....	22
Metacinnabarite from Knoxville, Napa County, California	22
Metacinnabarite from Cerro Gordo Mine, near Panoche, Fresno County, California.....	23
Sulphates from the Redington Quicksilver Mine, Knoxville, Napa County, California.....	23
Copiapite from Redington Mine, Knoxville, California	25
Copiapite from Sulphur Bank, Lake County, California	25
Stromeyerite from Calico, San Bernardino County, California	27
Chromiferous chlorite—Kotschubeite	27
Uwarowite	30
Scorodite	30
Note	31
Plates	33



ILLUSTRATIONS.

- PLATE I. Fig.** 1. Cinnabar crystal, analogue pole.
2. Cinnabar crystal, antilogue pole.
3. Cinnabar crystal.
4. Cinnabar crystal, with reentrant angle.
5. Crystal with gas inclusions.
6. Cinnabar crystal.
- II. Fig.** 7. Cinnabar crystal, analogue pole.
8. Cinnabar crystal with reentrant angle, antilogue pole.
9. Cinnabar crystals, with inclusion.
10. Cinnabar crystal, analogue pole.
11. Cinnabar crystal, antilogue pole.
- III. Fig.** 12. Subindividual on tectonic face.
13. Illustration of derivation of tetartohedral forms.
14. Section lines of tetartohedral forms of crystals 1 and 2 with basal plane.



LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE PACIFIC,
San Francisco, February 1, 1889.

SIR: We have the honor to transmit herewith through Mr. G. F. Becker, geologist in charge, Division of the Pacific, a paper on mineralogical studies of certain specimens which were collected during the recent examination of the quicksilver deposits of California.

In this material we are able to add somewhat to the previous knowledge of the habits of cinnabar crystals, and to give measurement which identify those crystal forms to which are ascribed the phenomenon of right and left rotation. Two new mineral species, into the composition of which chromium enters largely, are described and named, while the remaining matter is mostly confirmatory of previous observation to be found in the literature of mineralogy.

Very respectfully,

W. H. MELVILLE,
Chemist.

WALDEMAR LINDGREN,
Assistant Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey.



CONTRIBUTIONS TO THE MINERALOGY OF THE PACIFIC COAST.

BY W. H. MELVILLE AND W. LINDGREN.

CINNABAR CRYSTALS FROM NEW IDRIA, CALIFORNIA.

While examining the collection made by the U. S. Geological Survey at the New Idria quicksilver mines, our attention was drawn to a number of very minute cinnabar crystals having a somewhat uncommon habit. They were obtained from Superintendent J. W. C. Maxwell, who had washed them out from a soft ore occurring in the upper workings of the mine. The ore was in all probability a soft gray arkose sandstone impregnated with cinnabar. Examination showed that the apparently simple crystals have generally a thin tabular habit and present the forms $0R$, $-\frac{2}{3}R$, $-\frac{1}{2}R$, combined with tetartohedral faces of more or less complicated nature mostly in the zone of the terminal edge of $-\frac{2}{3}R$. The crystals are collective individuals built up of alternating layers of substance with opposite rotary power, dextro-gyre and levo-gyre, arranged with approximately parallel axes, the resulting structure being in many cases quite complex.

Long ago Des Cloizeaux¹ discovered that cinnabar belonged to the small class of substances which exhibit circular polarization, and that it rotates the plane of polarization more strongly than any other known substance. He also found that almost all of his sections cut perpendicularly to the axis did not belong to simple crystals, but showed a combination of right and left turning parts analogous to the well-known phenomena observed in quartz and its variety amethyst.²

In 1871 A. D'Achiardi³ discovered tetartohedral faces of

$$\frac{\infty P}{4} \text{ and } \frac{mP}{4}$$

but we are not aware that he determined their position. Dana⁴ records one scalenohedron, $\frac{1}{3}R3$.

¹Comptes Rendus, vol. 44, p. 876.

²Rammelsberg, in Handbuch der krystall. Chemie, Berlin, p. 81, states erroneously that only left turning crystals have been noted.

³Boll. Com. Geol. Ital., vol. 2, 1871, p. 163. The monograph of Schabus (Ber. Wien. Acad., vol. 6) is unfortunately not accessible to us.

⁴A System of Mineralogy, by J. D. Dana, fifth edition, 1884, p. 55.

The crystals hitherto found in the California quicksilver mines have either a prismatic or a rhombohedral habit and present no uncommon forms.¹ In the thin sections made by the Survey for the petrographical study of the quicksilver mines of the Pacific coast, the cinnabar whenever crystallized has a prismatic habit. The tabular crystals now under consideration are very small, almost microscopic, the diameters of which range from 0.05 mm to 0.6 mm, and the thicknesses from 0.02 mm to 0.2 mm. The trapezohedral faces which replace the terminal edges of the rhombohedrons are much broken and curved in the larger crystals, while in the smaller they are sometimes quite well developed and so large as to influence the general triangular habit of the tables. The individuals are often grouped in more or less complex bunches and regularly interpenetrate one another; two crystals may be frequently seen connected in such a way that one has grown either perpendicularly or obliquely into the basal plane of the other. There does not appear to be any general law governing these groupings.

On account of the tabular habit and their minute dimensions these crystals are admirably adapted for optical examination. They are translucent and deep red in color, the tint, however, being so dark that the phenomena can only be properly observed with low objectives. The apparently simple crystals present, when examined in parallel polarized light, considerable tectonic complications. On account of the feeble gyroid power of quartz this phenomenon can not be well observed in very thin sections of that mineral with common light. Cinnabar, on the other hand, rotating the plane of polarization more than quartz, according to Des Cloizeaux's measurements, fifteen to seventeen times as strongly, shows this property very well in the tabular crystals. The exact value of the angle is difficult to determine on account of the dark color in transmitted light. The crystal in Fig. 10 is drawn with the analyzer 26° to the right, its thickness is 0.09 mm. This gives a rotation of 289° for 1 mm, or 16.8 times as large as that of quartz, which for the red line C is 17.2. The arrangement of the dextro-gyre and levo-gyre parts is evidently governed by the law of regular grouping with parallel positive rhombohedrons, as in quartz, although there is reason to believe that the law is not strictly but only approximately true. The deviations at all events are small.

Generally speaking a composite crystal is formed of six sectors of 60° angle, whose directions of rotation are different, as illustrated in Figs. 7 and 8. The numbers of right or of left turning sectors are not constant, but may alternate regularly, or several adjacent sextants may be composed of the same substance. In the latter case they are usually separated by a narrow band of opposite rotary power and marked by a reentering angle between rhombohedral and trapezohedral planes (Figs. 4 and 7). With crossed nicols the sectors have a dark intermediate tint traversed by black radiating lines, indicating overlapping of

¹ E. Bertrand, Neues Jahrbuch, 1878, p. 637. (Redington mine, N. B., E.).

the different parts. These black bars move a short distance when the analyzer is turned. Deducted from the amplitude of the movement and the thickness of the crystal the dividing plane was found in some instances to have an inclination of 110° to 120° to the basal plane. Very frequently, however, the dividing surface is altogether irregular, and often only shadows moving indistinctly can be observed on turning the analyzer, as in Figs. 5 and 6. There are not uncommonly found alternating parallel layers within one sector, appearing with crossed nicols as a system of black equilateral triangles. Thin cuneiform pieces of different rotary directions are inserted in larger areas which are uniform in rotation. When the crystals rest on the basal plane they remain perfectly isotrope on turning the table of the microscope. Exceptionally a faint change in the intensity may be observed in isolated places, as in Fig. 9 at the point marked A in the dextro-gyre section. The cause is probably a local state of tension.

Gas and fluid inclusions have been recognized. The latter are small and have sometimes a movable bubble which does not change in volume on heating. The gas inclusions often take the form of negative crystals. In Fig. 8 a series of beautiful inclusions are represented. They surround a hexagonal figure in the interior of the crystal, the sides of which are parallel to the rhombohedral planes, and appear in transmitted light deep black on the red background of the crystal. A small red spot is to be seen in the center. This phenomenon is easily explained by the very high refracting power of cinnabar $\epsilon=3.20$, considerably higher than that of the diamond. The angle of total reflection is consequently about $20\frac{1}{2}^\circ$. In reflected light the inclusions appear brilliantly red on the now black background.

Crystal forms.—Rhombohedrons: In order to determine the symbols of the crystal faces an attempt was made to measure them under the microscope with micrometer screw and eye-piece. It was found, however, that the error in the very small vertical measurement was so large as to seriously impair the results. The next resort was the determination of the rhombohedral faces and the calculation of other forms, as far as possible, by means of their zone relations and horizontal measurements on the stage of the microscope. The rhombohedral faces and basal plane, in spite of the minute size of the crystals, gave tolerably good signals in a Fues goniometer, and in a series of the larger crystals the zone $[0R, R]$ was closely measured, as shown in the following table:

Interfacial angles $0R \wedge mR$.

Crystal.	$0 \wedge r(r = -R)$.	$0 \wedge r_{m'}(r_{m'} = -\frac{1}{2}R)$.	$0 \wedge r_{m''}(r_{m''} = -\frac{1}{2}R)$.	Remarks.
	$\circ$ $'$	$\circ$ $'$	$\circ$ $'$	
<i>a</i>	127 6	138 36	146 32	Calculated angles.
<i>b</i>		138 59	147	Reflex $r_{m''}$ elongated.
<i>c</i>		138 4		
<i>d</i>		138 56	147*	Reflex $r_{m''}$ elongated.
<i>e</i>	127 15	139 4		Reflex 0 duplicated.
<i>f</i>		138 28	147†	$r_{m''}$ indistinct.
<i>g</i>		138 42		
<i>h</i>		138 53		$\pm \infty R$ observed.
<i>i</i>	127 38	138 58	147 11	$r = +R$; $r_{m''}$ duplicated.
<i>k</i>		138 55	146 13	$+R$ observed.

* Closely.

† Approximate.

Crystal *f* was subjected to a revolution of 360° , and measurements were taken, as follows:

	Between normals.	Interfacial.
	$\circ$ $'$	$\circ$ $'$
$0R \wedge -\frac{1}{2}R$	41 18½	138 41½
$-\frac{1}{2}R \wedge 0R'$	138 42	41 18
$0R' \wedge -\frac{1}{2}R$	41 1	138 59
$-\frac{1}{2}R \wedge 0R$	138 58½	41 1½
	360	360

Reflected light, but no signal, was obtained from planes $-\frac{1}{2}R, -\infty R$ and possibly $+mR$ in this same zone.

Crystal *g* contained the prism face $-\infty R$ as shown by measurements in zone $[0R, -\frac{1}{2}R]$:

	Between normals.	Interfacial.
	$\circ$ $'$	$\circ$ $'$
$0R \wedge -\frac{1}{2}R$	41 7	138 53
$-\frac{1}{2}R \wedge -\infty R$	48 57	89 56

On crystal *h* the following measurements were recorded:

	Between normals.		Interfacial.
	$\circ$ $'$		$\circ$ $'$
$-\frac{1}{2}R \wedge -\frac{1}{2}R$	8 13	$-\frac{1}{2}R \wedge 0R$	138 58
$-\frac{1}{2}R \wedge 0R$	32 49	$-\frac{1}{2}R \wedge 0R'$	147 11
$0R \wedge 0R'$	180	$+R \wedge 0R$	52 22
$0R' \wedge +R$	52 22	$+R \wedge 0R'$	127 38

Also in the same zone reflected light from prism planes was observed. These latter planes are very narrow, occur along the lateral edges of the tabular cinnabar crystals, and are quite common, but in rare cases only can good signals on the goniometer be seen.

The rhombohedral face, $-\frac{2}{3}R$, is invariably perfect, and the basal plane, $0R$, is usually so; but the latter is oftentimes broken, the angle between its parts sometimes amounting to 1° . In some crystals the irregularities may be seen to follow the line between dextro-gyre and levo-gyre substance, indicating that the positions of the different parts are not strictly parallel. Planes of the rhombohedron, $-\frac{1}{2}R$, on the other hand, never give good reflections and are always striated. These striations are parallel to the combination edges of the rhombohedral face and the trapezohedral faces on either side. They are interesting and will be subsequently considered. Positive rhombohedral forms, $+mR$, are seldom present. In Fig. 9 one small face of $+\frac{2}{3}R$ (r_2) and one of $+\frac{1}{2}R$ (r_3) are noted.

In giving the negative sign to the dominant rhombohedron, we were led by considerations based on the nature of the trapezohedral faces, as well as by previous descriptions of the habit of cinnabar crystals.

The simple forms observed are tabulated thus:

Naumann.	Bravais-Miller (hkl).
$0R$	(0001)
$-\frac{2}{3}R$	$\kappa(02\bar{2}3)$
$-\frac{1}{2}R$	$\kappa(01\bar{1}2)$
$-R$	$\kappa(01\bar{1}1)$
$+R$	$\kappa(10\bar{1}1)$
$+\frac{2}{3}R$	$\kappa(20\bar{2}3)$
$+\frac{1}{2}R$	$\kappa(10\bar{1}2)$
∞R	$\kappa(10\bar{1}0)$

Of these forms $0R$ and $-\frac{2}{3}R$ are by far the most prominent.

Some typical crystals were selected, mounted in balsam and drawn under the camera-lucida. The greatest care was taken to reproduce a perfect image in the drawing, and this position of the crystals seemed best adapted to illustrate their irregularities and the relations of the trapezohedral planes to the other forms. The drawings could be made conveniently only with strong reflected light. Whenever special measurements of angles in a horizontal section were necessary, they were made by cross-hair and graduated table and were not taken from the drawings.

Tetarto-trapezohedrons.—Obliquely replacing the terminal edges of $-\frac{2}{3}R$ and $-\frac{1}{2}R$ (Figs. 1 and 3), there appeared a series of faces often broken and irregular, which from their position and connection with the dextro-gyre and levo-gyre substance of the cinnabar could only be regarded as tetartohedral forms of a dihexagonal pyramid. The interest

rose from the fact that in many individuals these forms were more largely developed, than in any cinnabar crystals heretofore described. Trapezohedral faces lying in the terminal zone of R have been observed in quartz crystals¹ and on hypoiodate of sodium² but there seems to be no record of such faces in a zone of more obtuse forms.

The relation between the sectors of different rotating power and the trapezohedral faces must now be considered. Applying the law of rhombohedral hemihedrism to the dihexagonal pyramid mPn , two scalenohedrons, $\pm \frac{mPn}{2}$ or $\pm m'Rn'$, are derived, which differ in position by 90° . Again applying the law of trapezohedral tetartohedrism to $\pm \frac{mPn}{2}$ we obtain four enantiomorph forms, $\pm r \frac{mPn}{4}$ and $\pm l \frac{mPn}{4}$ right and left trigonal trapezohedrons. Furthermore, the hexagonal pyramid of the second order, $mP2$, when subjected to trapezohedral tetartohedrism, yields two trigonal pyramids $r \frac{mP2}{4}$ and $l \frac{mP2}{4}$ which can be regarded as the limits between positive and negative trigonal trapezohedrons (Fig. 13).

The connection between the trapezohedral forms and the rotating direction in the case of quartz³ is as well known as that dextro-gyre crystals are modified by planes of

$$r \frac{mP2}{4}, +r \frac{mPn}{4}, -l \frac{mPn}{4}$$

and levo-gyre crystals by planes of

$$l \frac{mP2}{4}, +l \frac{mPn}{4}, -r \frac{mPn}{4}.$$

If the positive rhombohedron should be taken as negative, the first of the two divisions above would correspond to levo-gyre, and the second to dextro-gyre crystals.

In combination with a positive rhombohedron in right turning crystals⁴ (the face of $+R$ being held in front of the observer), $r \frac{mP2}{4}$ is placed on the right terminal edge obliquely towards the observer; $-l \frac{mPn}{4}$ lies between $r \frac{mP2}{4}$ and $-\frac{1}{2}R$, and $+r \frac{mPn}{4}$ replaces the combination edge of $+R$ and $r \frac{mP2}{4}$.

In levo-gyre crystals the planes $+l \frac{mPn}{4}$ and $-r \frac{mPn}{4}$ are placed on the other side of this terminal edge. In combination with a negative rhombohedron the relations are reversed, so that the dextro-gyre forms

¹ Websky on quartz crystals. Neues Jahrbuch, 1871, p. 732.

² Groth: Physik. Krystall, 1876, p. 302.

³ Groth: Physik. Krystall., 1876, p. 301.

⁴ P. Groth: Monatsbericht d. Berlin Akad., 1869.

here correspond in relative positions to the levo-gyre forms in the case of the positive rhombohedron.

In order to determine the nature of these trapezohedral faces and the form to which they belonged, measurements in the horizontal section were taken of the angles which the combination edges of ($-mR \wedge 0R$) made with those of the trapezohedral planes over the same basal plane. The crystal in Fig. 1 was chosen for this purpose and the angles on both the analogue and the antilogue poles were ascertained by means of cross-hair and stage of the microscope. The angles in Fig. 1 are designated α, β , etc.,¹ lettered in order; those in Fig. 2 are self-evident. In the first series of measurements low magnifying power was employed, and in the second, higher power for the determination of the angles where two trapezohedral faces formed re-entering angles. The latter should be accurate within one degree.

First series.		Second series.
Fig. 1.	Fig. 2.	Fig. 1.
o	o	o
$\alpha = 141$	Above $d = 140$	$\alpha = 138\frac{1}{2}$
$\beta = 100$	Above $c = 99$	$\beta = 99$
$\gamma = 137$	Above $b = 137$	$\gamma^1 = 139$
$\delta = 103$	Above $a = 104$	$\gamma^2 = 183$
$\eta = 135\frac{1}{2}$	Above $f = 136$	$\delta = 100$
$\theta = 104$	Above $e = 104\frac{1}{2}$	$\eta^1 = 130$
		$\eta^2 = 185\frac{1}{2}$
		$\theta = 103\frac{1}{2}$

The angles lettered γ^2 and η^2 are re-entering and are formed by two trapezohedral planes. Those edges forming γ^2 make with the combination edge ($-mR \wedge 0R$) on the right angles of 139° and 142° , respectively, and those forming η^2 make in the same way angles of 130° and $135\frac{3}{4}^\circ$, respectively. That these trapezohedral planes belong to the same class of derivatives from the scalenohedron and possess the same general symbol, is evident from Fig. 14, in which is shown the projection of the combination edges of the negative rhombohedron, $-mR$, and of the trapezohedral planes with the basal plane. The heavy lines represent the positions of these edges as they appear in Fig. 1, and the dotted lines the corresponding edges of Fig. 2 in their true relation to the crystal and Fig. 1. Figs. 13 and 14 show further that the trapezohedral planes in relation to $-mR$ have the general symbol $+r\frac{mPn}{4}$ and that the angles may vary in the basal section of (1) $+r\frac{mPn}{4}$ for α^2 from 120° to 150° , and for β from 90° to 120° ; β on left hand (2) $-l\frac{mPn}{4}$ for α from 150° to 180° , and for β from 60° to 90° ; β on left

¹ Compare Fig. 11.

² β = the less obtuse angle.

hand (3) $+l \frac{mPn}{4}$ for α from 120° to 150° and for β from 90° to 120° ; β on right hand (4) $-r \frac{mPn}{4}$ for α from 150° to 180° , and for β from 60° to 90° ; β on right hand. From the discussion above, the tetartohedral planes must belong to the form trigonal trapezohedron, and in this special case, Figs. 1 and 2, to $+r \frac{mPn}{4}$. Notwithstanding the large deviation

in the angular measurements of the basal section, as in α , γ^1 , η and in β , δ , θ , the trapezohedral planes, three above and three below, must constitute a complete form, and we are obliged to seek explanation of these discrepancies in the errors of measurements, in the distortions of the crystals, and in the fact that narrow planes, almost mere lines, which are present, may correspond to missing trapezohedral faces. Unfortunately, these narrow planes scarcely admit of a representation on the scale of the drawings, and much less of even an approximate measurement.

On studying the relations of the angles α and β to the other parts in many crystals, it was discovered that in the dextro-gyre sectors the angle β is always on the left side when the trapezohedral face is held towards the observer, and in levo-gyre sectors on the right. This, considered in connection with what has been said before concerning the positions of trapezohedral faces, can only be true if we consider the dominant rhombohedron negative, always of course under the supposition that the relation between differently rotating substance and the trapezohedrons (see p. 16) is the same as in quartz. If we reverse this, the rhombohedron must be considered positive. The most common face is that of $+l \frac{mPn}{4}$ in the left turning sectors and of $+r \frac{mPn}{4}$ in the right turning; negative trapezohedrons, where the angle $\beta < 90^\circ$ are quite rare; twice β was measured to 90° , corresponding to a section line of a trigonal pyramid.

The larger and more regular planes replacing the terminal edges of the rhombohedrons appear to be exactly in the zone of $[-\frac{2}{3}R, +\frac{1}{3}R]$, since under the microscope the combination edges of the trapezohedral face with the adjoining rhombohedral faces $-\frac{2}{3}R$ are parallel and make with the combination edge $(-\frac{2}{3}R \wedge 0R)$ on the right and left respectively equal angles of 150° in the horizontal projection. On the goniometer a faint, elongated flash of light, scarcely to be called a signal, was reflected from each of these planes in the zone $[-\frac{2}{3}R, -\frac{1}{3}R]$. Calculated from the observed values of β and the zone equation complex symbols of the trapezohedral forms are obtained. It was found by comparison of the different values that the position of the planes oscillates about the simpler forms $+r \frac{2}{5} \frac{P^3}{4}$ and $+l \frac{2}{5} \frac{P^3}{4}$, $\mu\mu''$ [2.4.6.15] corresponding to a value of $\beta = 100^\circ 53'$, but only once actually measured. The following

table shows the angles β , measured on several crystals, and the more obtuse angles α corresponding to these. The third column contains the measured angles α , and the fourth the symbols calculated from the angle β .

β measured. °	$\alpha = 240^\circ - \beta$	α measured.	Symbols, $+r \frac{mPn}{4}$
When $\beta =$	$\alpha =$		
93	147	.....	$\frac{1}{2}a : a' : \frac{1}{2}a'' : \frac{2}{3}c$
95	145	.....	$\frac{1}{2}a : a' : \frac{1}{3}a'' : \frac{1}{3}c$
99	141	.....	$\frac{1}{2}a : a' : \frac{1}{2}a'' : \frac{1}{3}c$
100	140	139	$\frac{1}{2}a : a' : \frac{1}{3}a'' : \frac{2}{3}c$
			$\{ 2.889a : a' : 1.582a'' : 0.407c$
100 53	139 7	(*)	$\{ 3a : a' : \frac{2}{3}a'' : \frac{2}{3}c$
			$\{ 2.999a : a' : 1.5a'' : 0.4c$
101	139	139½	$\{ 3a : a' : \frac{2}{3}a'' : \frac{2}{3}c$
			$\{ 3.015a : a' : 1.496a'' : 0.3996c$
102	138	.....	$\frac{1}{2}a : a' : \frac{1}{3}a'' : \frac{2}{3}c$
			$\{ 3.165a : a' : 1.462a'' : 0.396c$
103	137	137	$\frac{1}{2}a : a' : \frac{1}{2}a'' : \frac{2}{3}c$
104	136	136	$\frac{1}{2}a : a' : \frac{1}{2}a'' : \frac{2}{3}c$
105	135	134½	$\frac{1}{2}a : a' : \frac{1}{2}a'' : \frac{2}{3}c$
107	133	.....	$\frac{1}{2}a : a' : \frac{1}{3}a'' : \frac{2}{3}c$

* Not measured.

The frequent occurrence of trapezohedrons on quartz with complex symbols has often been commented on. Websky¹ has attempted to explain these by the theory of the induced faces, supposing the crystal to be built up of alternating layers of substance turned 180° around the vertical axis so that in this twin position $+R$ of one individual covers $-R$ of another. The trapezohedral forms in the upper layer are consequently influenced by those belonging to a different series in the lower layer, and, not being able to develop in their proper places, they take positions intermediate between these and those of the inducing face. This view seems not improbable in the present case under discussion.

Even in the more regular crystals, Figs. 1, 3, 7, the trapezohedral faces are seldom perfectly smooth, but generally slightly broken and curved. Figs. 7 and 10 show this tendency increased (t and d' , Fig. 6; u' , u , x , Fig. 10). Finally, in Figs. 5, 6, and 9 the faces are exceedingly rough, and broken into a number of irregular planes. Such phenomena have also been observed on the tetartohedral faces of quartz crystals.² Partially, at least, these irregularities may be explained by the hypoparallel position of the differently rotating parts composing the whole crystal.³

The fact that the basal plane is frequently broken, confirms the explanation just given. It appears peculiar, however, that the rhombo-

¹ See paper regarding Quartz Crystals from Strigau in Neues Jahrbuch, 1871, pp. 132, 785.

² Websky. Über Deformitäten an Quarz-krystallen. Neues Jahrbuch, 1870, p. 353.

³ Sadebeck. Krystallotektonik, p. 184.

hedral faces, $-\frac{2}{3}R$, do not show more markedly the effects of this hypoparallelism if it is really the cause of all the disturbances. On the goniometer the reflected signals from $-\frac{2}{3}R$ are frequently duplicated, but striations are wanting.

The tectonic face of $-\frac{1}{2}R$ has been alluded to. This face presents irregularities which under strong objectives appear as distinct figures formed by trapezohedrons and rhombohedrons, Fig. 12. Sometimes the whole face is covered by these protruding "subindividuals," bordered by vicinal planes,¹ causing either a rough (Drusigkeit) or a striated appearance, Fig. 12 *a, b*, Fig. 5. The tendency of $-\frac{1}{2}R$ to form vicinal faces is well shown in Fig. 8, and is illustrated by the irregularly running edge ($-\frac{2}{3}R \wedge -\frac{1}{2}R$). When re-entering angles are formed, which is very often the case, then the edge ($-\frac{1}{2}R \wedge 0R$) becomes broken and irregular, thus accounting in great measure for the large variation of β in the table on page 19. In Fig. 4 at the point marked *st'''* there is a coarse striation, which under strong objectives can be seen to be due to the combination of $-\frac{1}{2}R$ with a trapezohedron, the same which lies in zone $[-\frac{2}{3}R, -\frac{1}{3}R]$.

Description of crystals.—Crystal 1, Figs. 1 and 2. Rather uniformly built and principally of dextro-gyre substance. Angle β_d measured 99° , angle β_s , $103\frac{3}{4}^\circ$. Both trapezohedral planes have the general symbol $+r\frac{mPn}{4}$ and lie on either side of $+r\frac{\frac{2}{5}P\frac{3}{2}}{4}$. The symbols corresponding to the measured angles are, as shown on page 19, $+r\frac{\frac{15}{37}P\frac{11}{7}}{4}$ and $+r\frac{\frac{7}{13}P\frac{7}{4}}{4}$ respectively. There are other triangular trapezohedral planes, *m, n, p, q*, which belong to a more acute form than those determined. The symbols of these could not be ascertained either by measurement or by zone relations.

Crystal 2, Fig. 3, has two well-developed trapezohedral planes, and angle β_u measured 103° , and β_c 103° . Corresponding to this angle $c = +l\frac{\frac{9}{23}P\frac{10}{7}}{4}$ and $u = +r\frac{\frac{9}{23}P\frac{10}{7}}{4}$.

The upper edges show some irregular trapezohedral faces.

Crystal 3, Fig. 4. A re-entering angle is formed by $r_{//}$ and a broken trapezohedral face *k*. A narrow plane lying in the zone $[r_{//}, r_{//}]$ belongs probably to the trapezohedron of which *b* forms a part. There are present one right-handed and one left-handed trapezohedron,

$$b = +r\frac{\frac{5}{13}P\frac{11}{8}}{4} \text{ and } t = +l\frac{\frac{5}{13}P\frac{11}{8}}{4}, \text{ where } \beta_b \text{ and } \beta_t = 105^\circ.$$

Crystals 4 and 5, Figs. 5, 6. These crystals show how the irregularities of the trapezohedral faces increase as the complexity of the arrangement of dextro-gyre and levo-gyre parts increases. It does not seem improbable that most of the deviations from the correct positions of the

¹ Websky. Zeitsch. Deutsch. geol. Gesell., vol. 15, p. 677, Berlin. Sadebeck, Krystallotektonik, p. 195.

faces are caused by a conflict between series of forms of different rotating power belonging to cinnabar. $r_{III}(-\frac{1}{2}R)$, as well as $r_{II}(-\frac{2}{3}R)$ becomes very prominent and is characterized by striations and grooves.

Crystal 6, Fig. 7 and Fig. 8 opposite poles. Built of alternating sectors with smooth trapezohedral faces.

Angle measured.	Fig. 6a.	Fig. 6b.	Symbol.
β_0	105	.....	$+r_{13}^{\frac{1}{2}} \frac{P_{13}^1}{4}$
β_1	105	.....	$+l_{13}^{\frac{1}{2}} \frac{P_{13}^1}{4}$
β_2	.....	104	$+r_{12}^{\frac{1}{2}} \frac{P_{12}^1}{4}$
β_3	.....	102	$+l_{12}^{\frac{1}{2}} \frac{P_{12}^1}{4}$
β_{III}	.....	97	$+r_{11}^{\frac{1}{2}} \frac{P_{11}^1}{4}$

In Fig. 7, at the lower right-hand of the drawing a re-entering angle appears, causing a thin wedge of dextro-gyre substance to occur in a levo-gyre sector. At this part of the crystal there are three planes, t^2 , t^3 , t^4 , the special symbols of which could not be determined. The plane t^2 belongs to the form $+l \frac{mPn}{4}$, and t^3 to $-r \frac{mPn}{4}$. The triangular planes o , o' , p are probably more acute trigonal trapezohedrons. The re-entering angle at d was so irregular and the combination edges with $0R$ so broken that no reliable information could be obtained concerning the planes. The opposite pole, Fig. 8, does not present such complex combinations of forms.

Crystal 7, Fig. 10, is very similar to crystal 7, but almost wholly levo-gyre. Measured, $\beta u = 103^\circ$, $\beta x = 95^\circ$. Therefore

$$u = +l_{23}^{\frac{2}{3}} \frac{P_{23}^{10}}{4}, \text{ and } x = +l_{19}^{\frac{2}{3}} \frac{P_{19}^{10}}{4}$$

The remaining planes were not determinable. Fig. 11 represents the antilogne pole. β , β' , β'' measured 106° , 107° , 103° , respectively.

Crystal 8, Fig. 9, is levo-gyre for the most part, and exhibits beautiful gas inclusions. The usual trapezohedrons are here present with combination edges very much broken. Plane g is probably a trigonal pyramid, for angle $\beta = 90^\circ$, while the measured angle $\alpha = 150^\circ$ ($g : r_{III}$ on the right).

The form is then $r \frac{mP2}{4}$; $r_2 = +\frac{2}{3}R$ and $r_3 = +\frac{1}{2}R$.

CINNABAR CRYSTALS FROM SULPHUR BANK, LAKE COUNTY, CAL.

In the collection of the Survey appears a coating of cinnabar crystals upon an argillaceous rock, which has resulted from the decomposed and disintegrated basalt abounding in the quicksilver workings at Sulphur Bank. Throughout this rock run seams of persulphide of iron, probably *marcasite*, and patches of this mineral form the lining of cavities

upon which have grown calcite crystals. Cinnabar is also very abundant in the mass of the rock, and in many places has crystallized contemporaneously with the calcite. The crystals in the coating are brick-red, possessing a rather metallic luster, by no means so highly adamantine as the tabular crystals from New Idria, while the powder yields a brilliant vermillion. The crystals, varying in diameter from 0.5 to 0.75^{mm}, were found to be simple rhombohedrons with no other hexagonal modification. The rhombohedral faces are curved much as they often are in mineral dolomite, and, owing to this fact, as well as to the dull luster, great difficulty was experienced in obtaining close measurements. The most reliable angular measurements were those taken over the terminal edge of the rhombohedron. This angle is 74° 40' between normals, the mean of over a dozen determinations, from which is deduced the symbol $\pm \frac{3}{4}R$. The calculated angle for $\pm \frac{3}{4}R$ is 75° 8½' between normals, or 104° 51½' interfacial.

CINNABAR CRYSTALS FROM KNOXVILLE, NAPA COUNTY, CAL.

Large masses of marcasite, which is often vesicular and carries fragments of quartz and opal, occur in the quicksilver deposits at Knoxville. The marcasite is frequently crystallized in the cavities. Metacinnabarite forms the greatest part of the sulphide of mercury which these specimens contain, while upon its surface brilliant needles of cinnabar have crystallized sometimes in tufts and again in irregular network. The needles vary in length from 0.5 to 2^{mm} and their diameter is rarely greater than 0.1^{mm}. Excellent measurements were obtained which resulted in the identification of the crystal forms $-\frac{1}{2}R$ (or $+\frac{1}{2}R$) and the hexagonal prism ∞P (or $\pm \infty R$). The angle between normals $-\frac{1}{2}R \wedge -\infty R = 43^\circ 26'$, interfacial $136^\circ 34'$. The calculated angle for $(-\frac{1}{2}R \wedge 0R) = 46^\circ 34'$ between normals, $133^\circ 26'$ interfacial ($133^\circ 24'$ Dana) This habit of cinnabar has been observed also by E. Bertrand. (See note p. 12.)

CINNABAR CRYSTALS FROM NEW ALMADEN, CAL.

Many crystals were examined which were found on specimens from New Almaden mines. These stout and brilliant crystals usually exhibited the forms $0R, -\frac{1}{2}R, -\frac{3}{2}R, -2R, \pm \infty R$; one had the form $+mR$. An angular measurement was obtained, $-mR \wedge 0R = 75^\circ 7'$ (normals), which corresponds to the form $-\frac{1}{5}R$. This form has not been given by Dana, and by us was observed only once.

METACINNABARITE FROM KNOXVILLE, CAL.

The metacinnabarite associated with the needles of cinnabar previously described occurs in seams from 2 to 4^{mm} wide, is easily detached and but slightly contaminated with quartz and possibly marcasite. Occasionally small nodules of metacinnabarite are seen on the specimens and appear to be formed of crystals which present dull and curved

faces baffling all attempts at recognition and identification. In the following analysis the mercury, iron, and silica were determined, and the amount of sulphur was calculated for the metals, analysis (I) on the assumption that iron is combined as FeS ; (II), that FeS_2 is the combination:

	I.		II.
	<i>Per cent.</i>		<i>Per cent.</i>
HgS	98.48	HgS	98.48
FeS	0.691	FeS ₂	0.942
SiO ₂	0.707	SiO ₂	0.707
	99.878		100.129

In order to ascertain if possible in which state of combination the iron existed in the sample, two experiments were made. Crystals of marcasite were taken from the same specimen which furnished the sample for analysis, and the fine powder was boiled with dilute hydrochloric acid ($\text{HCl} : 10\text{Aq}$). Appropriate tests gave barely a trace of sulphureted hydrogen. On the other hand a portion of the sample employed for analysis yielded an abundance of this gas when slightly heated with the dilute acid. In the absence of other sulphides the conclusion must follow that the iron exists wholly or in part in the form of protosulphide.

METACINNABARITE FROM CERRO GORDO MINE, CAL.

At the Cerro Gordo Mine, 11 miles west of Panoche, Fresno County, was found a specimen of metacinnabarite associated with chalcodony and crystallized quartz. The quantity collected for analysis amounted only to 0.0159 grams, and this sample contained a small percentage of cinnabar. 95.62 per cent. HgS was obtained on analysis, the residue, 4.38 per cent., consisted of quartz and a little iron which was undetermined.

SULPHATES FROM THE REDINGTON QUICKSILVER MINE, KNOXVILLE, CAL.

The mass of the rock specimen is a black opal which is much fractured. The seams contain three distinct salts.

(1) Small black crystals belonging to the isometric system and presenting the forms 0 and $\infty 0$. The substance is a double sulphate of iron and potassium, an alum in which both the ferrous and the ferric states of iron occur.

(2) The mass is fibrous, often so fine that the fibers can hardly be distinguished under the microscope; seldom are seen massive portions with crystalline structure. The color is pale purple. The parallel-fibrous aggregates are sometimes white with silky luster and only *purple on the surface* perpendicular to the fibers. Under the micro-

scope they are colorless with no visible crystalline form. The system of crystallization is probably triclinic, as extinctions parallel to the fibers are never obtained. Extinction 13° to 38° . Double refraction feeble. Specific gravity=1.761. Soluble in water.

<i>Analysis.</i>	
H ₂ O at 100° C.....	27.093
H ₂ O above 100° C.....	14.340
SO ₃	35.352
Al ₂ O ₃	5.136
Cr ₂ O ₃	7.512
Fe ₂ O ₃	0.186
FeO.....	4.579
NiO.....	1.001
MnO.....	trace.
MgO.....	1.850
Residue.....	3.457
	100.506

The atomic ratio is therefore $R^{II} : R^{VI} : S^{VI} : H_2 = \frac{1}{4} : \frac{2}{3} : 2\frac{1}{4} : 4\frac{1}{2}$, and the simplest symbol $9RO \cdot 8R_2O_3 \cdot 33SO_3 \cdot 171H_2O$. A portion of this large amount of water can be accounted for in the moisture of the sample. There seems to be a possibility of an isomorphous mixture of different sulphates in this substance, but a mechanical separation of the massive from the fibrous portions was quite out of question. We propose for this mineral the name Redingtonite.

(3) This sulphate coats the purple salt in small quantities. Under the microscope it is found to consist of rhombic tables with angles of 78° and 102° . The system is rhombic. The cleavage is excellent, parallel to OP , and good parallel to $\alpha P'$ and $\alpha P \infty$. The color is greenish yellow; the mineral is somewhat dichroic; the color being most intense when the short diagonal of the tables is parallel to the principal section of the nicols. It is doubly refracting. The tables are too small to show the emergence of the optic axis. Tests with mica plates show, however, that of the two axes of elasticity lying in the basal plane the one parallel to the brachydiagonal is the larger. This also agrees with copiapite, which is negative.

The following analysis was made with 0.1482 grams material which was separated from associated substances as well as possible. The water above 100° C. was determined by difference.

H ₂ O at 100° C.....	9.296
H ₂ O above 100° C.....	17.596
SO ₃	35.905
Cr ₂ O ₃	7.409
Al ₂ O ₃	4.835
Fe ₂ O ₃	15.360
FeO.....	3.813
NiO.....	0.835
MgO.....	3.216
Residue.....	1.735
	100.00

The atomic ratio is $R^{II} : R^{VI} : S^{VI} : H_2 = \frac{3}{16} : \frac{7}{6} : \frac{11}{4} : 3$. From its optical and some of its chemical characters there are evidences of its isomorphism with copiapite from Knoxville, a mineral hereafter described, and a comparison of the atomic ratio with that obtained by analysis of the latter mineral shows rather close analogy. This sulphate is more basic than that, and its composition indicates a derivation from other sources than persulphide of iron. We propose for this mineral the name Knoxvillite.

COPIAPITE FROM REDINGTON MINE, KNOXVILLE.

The specimen of copiapite consists of a soft mass composed of microscopic scales and crystalline particles, the color of which is sulphur-yellow. The optical properties of the mineral species have been described by E. Bertrand¹ and this specimen confirms his description in all important points.

The mineral is rhombic, and the microscopic fragments are mainly cleavage pieces from 0.04 to 0.2^{mm} in diameter. The cleavage is perfect parallel to OP , and fairly good parallel to ∞P . The angles of the prism are 78° and 102° . The plane of the optic axes is $\infty P\alpha$. The second median line is perpendicular to OP . The double refraction is negative. The pleochroism is quite distinct, especially on OP ; a slightly greenish-yellow, b nearly colorless, c yellowish.

Analysis.

H ₂ O	30.43
SO ₃	39.97
Fe ₂ O ₃	26.54
FeO	0.46
MnO	0.21
MgO	3.06
	100.67

Atomic ratio $R^{II} : R^{VI} : S^{VI} : H_2 = 1 : 6 : 18 : 20$, corresponding to the formula



COPIAPITE FROM SULPHUR BANK, LAKE COUNTY, CALIFORNIA.

In the surface mines of the quicksilver deposits at Sulphur Bank bright red cinnabar is associated with the products of the decomposition of marcasite. Among these are ferrous sulphate, a white silky sulphate of iron and alumina, and a yellow ferric sulphate. The latter salt was studied in order to ascertain how closely it approached the

¹ Groth's Zeitschr. für Krystall. u. Min., vol. vi, 1882, p. 296.

copiapite from Knoxville in its characters. Under the microscope it entirely resembled this mineral, and the description above given for copiapite answers for this ferric sulphate. The following analysis was made, in which the water above 100° C. was determined by difference:

H ₂ O	29.575
SO ₃	38.820
Al ₂ O ₃	0.371
Fe ₂ O ₃	26.792
FeO	3.277
MnO.....	trace.
CaO	0.255
MgO.....	0.156
Residue.....	0.754
	100.000

The atomic ratio is $R^{II} : R^{VI} : S : H_2 = 1 : 10 : 30 : 33\frac{1}{3}$, corresponding to the formula $\frac{3}{2}RO \cdot 5R_2O_3 \cdot 15SO_3 : 50H_2O$.

Since all these sulphates, with the exception of redingtonite, were yet damp when taken for analysis, the moisture which was thus mechanically occluded by the salts can not be considered in the discussion of their formulæ. The atomic ratios calculated for the anhydrous salts on the basis of 100 per cent. are tabulated as follows:

Purple sulphate, Redingtonite, anhydrous...	$R^{II} : R^{VI} : S^{VI} = 0.44 : 0.98 : 4.77$
Green sulphate, Knoxvilleite, anhydrous.....	$R^{II} : R^{VI} : S^{VI} = 0.40 : 1.61 : 3.77$
Copiapite, anhydrous.	$R^{II} : R^{VI} : S^{VI} = 0.24 : 1.42 : 4.27$
Yellow salt, Sulphur Bank, anhydrous.....	$R^{II} : R^{VI} : S^{VI} = 0.16 : 1.47 : 4.18$

	Purple sulphate.	Green sulphate.	Copiapite.	Yellow sulphate.
Atomic ratio.....	2 : 4 : 19	12 : 36 : 90	6 : 36 : 102	6 : 54 : 150
Formulae	$6RO \cdot 4R_2O_3 \cdot 19SO_3$	$6RO \cdot 6R_2O_3 \cdot 15SO_3$	$3RO \cdot 6R_2O_3 \cdot 17SO_3$	$3RO \cdot 9R_2O_3 \cdot 25SO_3$

It is evident that the yellow ferric sulphate is identical with the copiapite from Knoxville, because the ratio of the atomicities of the total base to SO_3 is practically the same; i. e., in copiapite, 21 : 17; in the yellow salt, 20 : 16 $\frac{1}{3}$. The purple salt scarcely belongs to this scheme, because it proves to be a neutral sulphate according to its properties as well as by the atomic ratio first given in the description of the mineral species. Its rather compact state does not admit of the occlusion of much moisture. The other sulphates are loose in texture, and a fair comparison of their composition can be attained only through the above scheme. These sulphates are then basic sulphates, and in the anhydrous state are closely represented by the formulæ in the above table.

STROMEYERITE FROM CALICO, SAN BERNARDINO COUNTY, CALIFORNIA.

On the lower levels of the Silver King Mine in Calico, a sulphide of copper and silver was found, which by the following analysis proved to be stromeyerite:

Ag	53.964	which requires 8.018 S as Ag_2S	
Cu	28.575	which requires 7.223 S as Cu_2S	
Fe	0.264		
S	15.512		15.241 theoretical S.
Residue	1.552		
	<u>99.867</u>		
Theory requires for $\text{Ag}_2\text{S} \cdot \text{Cu}_2\text{S} \dots$			
		Ag =	53.084
		Cu =	31.148
		S =	15.768
			<u>100.000</u>

The residue was mostly barite with a very little quartz. Comparison with the analyses of this mineral species which Dana¹ has tabulated, shows that the specimen under examination differs greatly, in composition, from those from Arizona, while it more nearly approaches specimens from localities in Siberia and Silesia. The analyses of stromeyerite from Arizona show a variation in silver from 7.42 to 14.05 per cent; in copper from 72.73 to 64.02 per cent.

The specific gravity of our specimen, 6.28, was found to be the same as that given by Dana for the mineral species. The mineral is dark-steel gray on fresh fracture, but tarnishes somewhat on exposure. It is associated with barite, malachite, and contains widely separated and minute areas of a brown oxide of manganese.² Other minerals found in the same mining region are as follows:

Cerargyrite (horn-silver) as brown coatings; embolite (chloro-bromide of silver) greenish-yellow coatings, and crystalline aggregates, combinations of 0, $\infty 0 \infty$, and $\infty 0$; chalcopyrite; chrysocolla, usually microscopic; malachite; cerussite; pyrolusite; barite, massive and tabular crystals; calcite.

CHROMIFEROUS CHLORITE—KOTSCHUBEITE.³

The great serpentine belt crossing the North Fork of the American River above Dutch Flat contains several deposits of chromite, some of which are worked on a small scale. While examining the ore from one of these occurrences—Green Valley, in the cañon of the American River, below Towle's on the Central Pacific Railroad—coatings of a micaceous

¹ A System of Mineralogy, by J. D. Dana, ed. of 1883, p. 54.

² W. Lindgren: Trans. Am. Inst. Min. Engineers, Feb., 1887.

³ This article and those following have already appeared in print, having been published in the Proceedings of the California Academy of Sciences, Dec. 20, 1887, under the title, "Contributions to the Mineralogy of the Pacific Coast," by Waldemar Lindgren, U. S. Geol. Survey.

mineral of a beautiful peach-blossom color, together with smaller pieces of the same mineral, were found in the massive state. The substance proved to be a chlorite, and is most closely allied to that variety of clinocllore to which Kokscharow¹ gave the name kotschubeite. With a magnifying glass the micaceous coatings are seen to be composed of thin hexagonal tables from 0.2^{mm} diameter down to the smallest dimensions, often roughly arranged in rosette form and in smaller fibrous masses, the latter being mixed with minute grains of uwarowite and chromite. The crystals cleave perfectly parallel to the hexagonal section, and appear to consist of a basal plane and rhombohedrons, one of which presents small striated faces. No accurate measurements could be obtained by means of the goniometer, or the micrometer and micrometer screw.

Under the microscope the tables, when resting on their bases, are pale purple and transparent, and between crossed nicols the crystals prove to be double-refracting and biaxial. The tables, apparently strictly hexagonal, are twinned monoclinic crystals, the most regular forms being usually divided into six sectors with a common apex in the center and with their axes of elasticity in different position. The colors of interference are low on the base, not exceeding the grays of the first order; those of the fibrous aggregates are more vivid, more so in fact than is usual with the chlorites.

In convergent light the plane of the optic axes is found in each sector to be parallel to its base; angle of the optic axes quite large, probably about 30°. Double refraction positive. The character of the dispersion can not be well observed on account of the small size of the crystals.

The acute bisectrix stands nearly normal to the base *OP*, and the extinction of the fibers is consequently quite small. Pleochroism distinct: *a* and *b* purplish, *c* (vibrating perpendicularly to *OP*) yellowish red.

Streak of the mineral, white; luster of cleavage face, somewhat pearly. $H=2$. G (massive variety)=2.69.

Before the blow-pipe the mineral becomes greenish white, and is fusible on the edges with great difficulty. With fluxes strong chromium reactions.

In the following analysis the sample was quite free from associated chromite and uwarowite. In order to facilitate comparison two analyses follow, one from Dana's Mineralogy, an analysis of k  mmererite; the other an analysis of kotschubeite by von Leuchtenberg.

¹ Bull. Acad., St. Petersburg, 1861, p. 369.

COMPARISONS OF CHLORITES.

		Kämmererite, Texas, Pa.	Kotschubeite, Ural.
Loss at 105° C.	0.365		
Loss above 105° C.	12.678	13.20	12.63
} 13.043			
SiO ₂	31.740	31.31	32.67
Cr ₂ O ₃	11.392	2.98	4.09
Al ₂ O ₃	6.741	12.84	13.18
Fe ₂ O ₃	.....	.....	2.22
FeO	1.231	2.46	.....
NiO	0.487	0.45	.....
CaO	0.183	0.82	.....
MgO	35.178	35.02	35.65
	99.995	99.08	100.44

The two forms of chlorite, penninite and clinochlore (ripidol according to Rammelsberg, substantially the same compos differ only in their crystallization, penninite being hexag clinochlore, monoclinic. Both have varieties rich in chrom corresponding to penninite being kämmererite from the Ural well-known locality, Texas, Pa. It has been proved to be ur Des Cloizeaux¹ and J. P. Cooke.² Various authors have also d it as rhodophyllite, chromchlorite, rhodochrom. The chr variety of clinochlore, kotschubeite, from the Urals, has been by Nicholas von Leuchtenberg,³ but has not been noticed from locality, and its occurrence in California is therefore not withou

Von Leuchtenberg arrives at the conclusion that kotschu variety of clinochlore, but differs from it in the inclination of bisectrix to the normal of the base; while this value amounts 16° in clinochlore, it has been measured to 1° to 2° in kotschub same writer's description applies equally to the California sp to the optical characters, but the crystal form differs. The from the Ural had the form of hexagonal pyramids, and was a composed of simple crystals, while that here described occ tables composed of three individuals, and twinned accordir well known law of clinochlore, so as to appear as hexagonal In the position of the optical axis the crystals most resembl clinochlore from Texas, Pa., described by Cooke.

A further and notable difference from Kokscharow's kots and, indeed, from any known chromiferous chlorite, is in the percentage of Cr₂O₃; v. Leuchtenberg found 4.09 per cent, highest amount of Cr₂O₃ in kämmererite is 5.50 per cent. Th of the California mineral shows more than twice that am 11.392 per cent Cr₂O₃, replacing Al₂O₃, but in other respects well with those of kämmererite and kotschubeite above.

¹ Mineralogie, vol. 1.

² Am. Jour. Sci., 2d series, vol. 44, p. 201.

³ Bull. Acad. Imp. Sci., St. Petersburg, vol. 13, 1869, p. 34.

In the collection of the California State Mineralogical Museum there is one specimen of chromite from a locality near Jackson, Amador County, covered with a thin coat of massive, peach blossom colored chlorite. Whether it is k  mmererite or kotschubeite is difficult to decide.

UWAROWITE.

Together with the kotschubeite, mixed with it as small grains or lining small fissures in chromite as almost microscopic crystals with brilliant faces, there occurs a deep emerald-green garnet. Under the microscope the crystals prove to be almost perfect dodecahedrons; with fluxes, strong chromium reaction. H. above 6. Refraction very strong. Between crossed nicols some grains are isotropic, but the largest number are faintly double-refracting, some of these showing an approximate division into sectors. Garnets, as well known, often present abnormal phenomena of double refraction, and, according to Rosenbusch,¹ uwarowite always shows these optical anomalies. Uwarowite is known to occur on chromite from New Idria, California.

A green chromium mineral, also on chromite, from the vicinity of Livermore, California, proved to be uwarowite in microcrystalline form, and not trautwinite as supposed.

Trautwinite² is associated with chromite from Monterey County. In chemical composition it approaches uwarowite, but differs, according to Goldsmith, in crystal form, since it is hexagonal; it is, moreover, very soft, while uwarowite has a hardness approaching 7.

SCORODITE.

At Steamboat Springs, Nevada, metalliferous veins occur with arsenopyrite among other minerals in the metamorphic series. In cavities and cracks of this mineral coatings of a leek-green scorodite are found, which under the microscope often show perfect crystals with the usual combination of pyramid and pinacoids {111}, {010}, {100}. Refraction and double refraction very strong. This mineral has recently been found by A. H. Chester at the Hornsilver Mine, Utah,³ and as deposit from arsenical thermal waters in the Yellowstone Park by Mr. A. Hague,⁴ of the U. S. Geological Survey.

¹ *Microskopische Physiographie der Mineralien*, 2d ed., 1885, p. 269.

² E. Goldsmith: *Proc. Acad. Sci., Phila.*, 1873, pp. 9, 348, 365.

³ *Am. Jour. Sci.*, vol. 33, 1887, p. 290.

⁴ *Ibid.*, vol. 34, 1887, p. 171.

NOTE.

Since the foregoing was written, cinnabar crystals from the Avala Mountains, Servia, have been described by A. Schmidt, in *Földtani Közlöny*, xvii, 551-555, 1887, and in *Zeitschr. f. Kryst.* Bd. xiii, 433-449, 1888, and an extract from the paper appeared in *Neues Jahrb. f. Mineralogie*, Bd. 1, 45, 1889. This admirable treatise contains an exhaustive description of complex crystals, upon which trapezohedral planes were observed, much like those on the crystals from New Idria. The Servian material was much more perfect, with larger individual forms than ours, thus admitting of angular measurements which we found impossible to make. The dominant forms, viz, the basal plane and rhombohedrons, are the same from the two localities, while among the trapezohedrons only one which we observed, $+r\frac{5}{13}P\frac{11}{5}$, approximates one of Schmidt's, $+r\frac{4}{13}P\frac{3}{2}$. As a rule we found far more complex forms, and, as the table on page 19 indicates, a slight deviation of angle makes considerable difference in the symbol. The reentering angles and tectonic faces apparently suggested many more trapezohedron planes than are recorded, but with objectives of very high power these planes were proved to be parallel to others whose symbols were established. In all about twelve different trapezohedrons were fully identified. In general, then, the habits of the cinnabar crystals from New Idria and Servia should be considered identical.



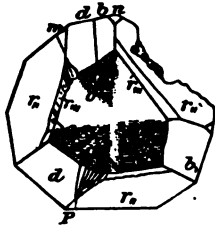
PLATES.



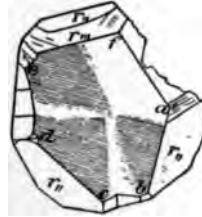
PLATE I.

PLATE I.

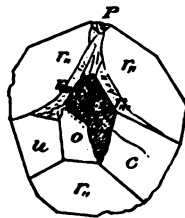
- FIG. 1. Cinnabar crystal, analogue pole.
2. Cinnabar crystal, antilogue pole.
3. Cinnabar crystal.
4. Cinnabar crystal with reentrant angle.
5. Crystal with gas inclusions.
6. Cinnabar crystal.
-



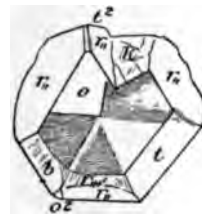
1



2



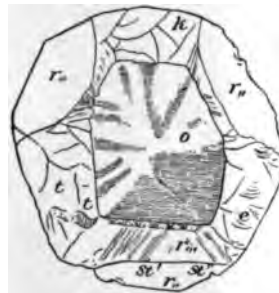
3



4



5



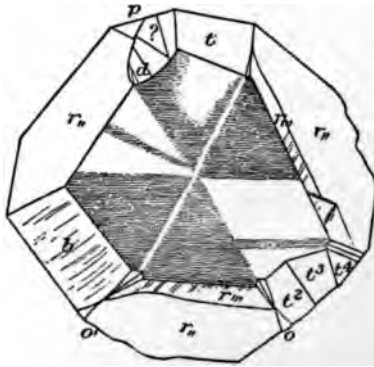
6



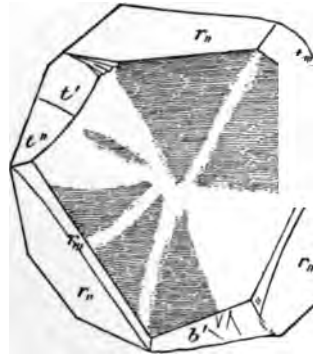
PLATE II.

PLATE II.

- FIG. 7. Cinnabar crystal, analogue pole.
8. Cinnabar crystal with reentrant angle, antilogue pole.
9. Cinnabar crystals, with inclusion,
10. Cinnabar crystal, analogue pole.
11. Cinnabar crystal, antilogue pole.
-
-



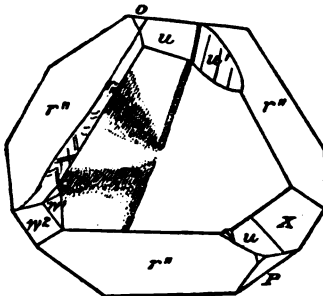
7



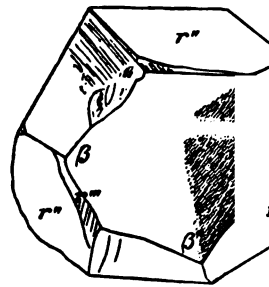
8



9



10



11



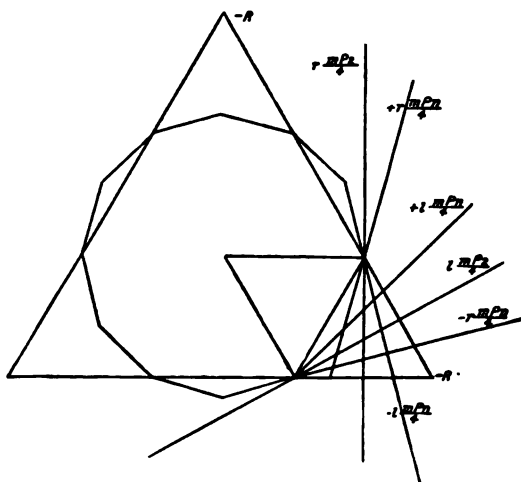
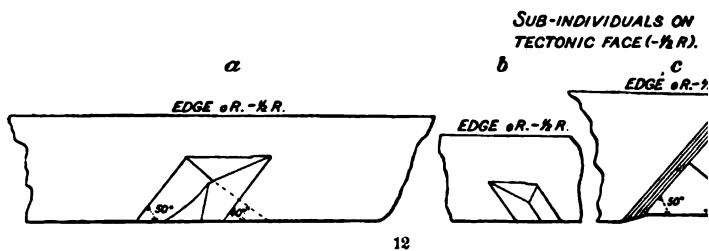
PLATE III.

PLATE III.

FIG. 12. Subindividual on tectonic face.

13. Illustration of derivation of tetartohedral forms.

14. Section lines of tetartohedral forms of crystals 1 and 2, Plate I, with basal plane.





To avoid fine, this book should be returned on
or before the date last stamped below

--	--	--

Stanford University Libraries



3 6105 126 652 903

